Baltic Forum for Innovative Technologies for Sustainable Manure Management

KNOWLEDGE REPORT

National Scenarios, Best Practices and Recommendations for Manure Energy Use in the Baltic Sea Region

By Sari Luostarinen (ed.)

- WP6 Energy Potentials of Manure

- December 2013

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Baltic Manure WP6 Energy potentials

National Scenarios, Best Practices and Recommendations for Manure Energy Use in the Baltic Sea Region

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Preface

In this report, scenarios for harnessing the energy content of manure as biogas are presented for the Baltic Sea Region (BSR). The scenarios build on the energy potentials estimated for each BSR country in a previous report (Luostarinen 2013) and take into account the different political and regulatory conditions and the current manure energy use in each country. The aim is to show direction into which the countries could start moving into in order to make use of manure energy and the other benefits of manure-based biogas (nutrient recycling, emission mitigation). Also, the location of manure and thus its energy content is shown on maps giving advice into locating especially larger manure-based biogas plants. A Baltic Manure Vision of having 25% of all manure in biogas production by 2025 was also set and the preconditions for reaching this vision are discussed country by country.

As a wrap-up of all work done for manure energy during the three years of Baltic Manure project is also presented. The main issues of manure energy requiring development and attention in the BSR are discussed in more detail and overall recommendations for implementing and supporting manure energy, especially manure-based biogas are given.

This report was compiled and edited by Sari Luostarinen (work package leader, MTT Agrifood Research Finland). All partners from MTT (Finland), JTI (Sweden), Rostock University (Germany), POMCERT (Poland), LRCAF (Lithuania), LLU (Latvia) and EMU (Estonia) provided the necessary data for their respective countries and authored the chapters related to them. Moreover, Mats Edström (JTI), Andrea Schüch (Rostock University) and Sari Luostarinen (MTT) authored the sections on solutions for solid manure digestion, use of co-substrates and the requirement for post-digestion.

This report was produced as part of work package 6 “Manure Energy Potentials” in the project “Baltic Forum for Innovative Technologies for Sustainable Manure Management (Baltic MANURE)”. The project aims at turning manure problems into business opportunities, one of which is using biogas technology as part of manure management. The project is partly funded by the European Union European Regional Development Fund (Baltic Sea Region Programme 2007-2013).

December 2013

the authors

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1 Introduction

Sari Luostarinen

There are 187 million tons of cattle, pig and poultry manure in the Baltic Sea Region, as estimated previously (Germany: only the states Mecklenburg Western-Pomerania and Schleswig-Holstein included; Luostarinen 2013). Of this, only approximately 4.2 million tons (excluding Germany) is directed to biogas plants at the time of writing (autumn 2013). Thus, only a little over 2% of the manure available in the BSR is digested in biogas plants. As the theoretical energy potential of all this manure is 38-74 TWh/a as biogas and even after exclusion of smaller farms 17-35 TWh/a (Luostarinen 2013), a significant amount of renewable energy is currently not being utilised.

The conditions for manure-based biogas vary country-specifically. First of all the ratio of slurry and solid manure varies significantly and affects the technological choices of manure digestion. For instance, in Denmark 80% of all manure is slurry. This makes biogas production from manure technologically simple as the processes are the most developed for such materials. On the other hand, it requires transportation of a lot of water in the slurry in case of farm co-operative biogas plants and makes the profitability of manure-based biogas a challenge. Slurry requires large digester volumes and the biogas production per digester volume is low. On the other hand, in Poland 90-95% of manure is solid and the technologies for digesting it are not well-developed. New solutions are needed.

The political framework surrounding manure-based biogas differs from country to country. While in other countries there is a strong will to increase biogas production and solutions are being planned and implemented to support it, other countries see it as too insignificant as to support it effectively. The financial support systems and their stability differ. Most of the support mechanisms focus on guaranteed prices for the renewable energy produced, while less incentives are directed to the other positive effects of manure-based biogas, such as emission mitigation and nutrient recycling.

In this report, national scenarios for harnessing the manure energy potential as biogas are created for all BSR. The methodologies for this task differ from country to country, as do the conditions, but all scenarios aim at replying in the following issues:

- locations of manure and thus its energy content in each BSR country
- possible locations for manure-based biogas plants
- possible amount of manure-based biogas plants in different scales
- estimated investment costs and potential for job opportunities

Moreover, a Baltic Manure VISION for manure energy was created:

25% of all manure into biogas plants by 2025.

Each national scenario aims at roughly describing by what measures this could be reached taking into account the country-specific conditions.

2 Finland

Saija Rasi, Eeva Lehtonen & Sari Luostarinen

2.1 Background

In Finland, there is about 13.5 million tons of manure in total produced each year (Fig. 2.1). Most of the manure is utilised as an organic fertiliser as such and only a small portion is being processed in any way. Energy use of manure is scarce. There are only a few biogas plants digesting manure (Luostarinen 2013).

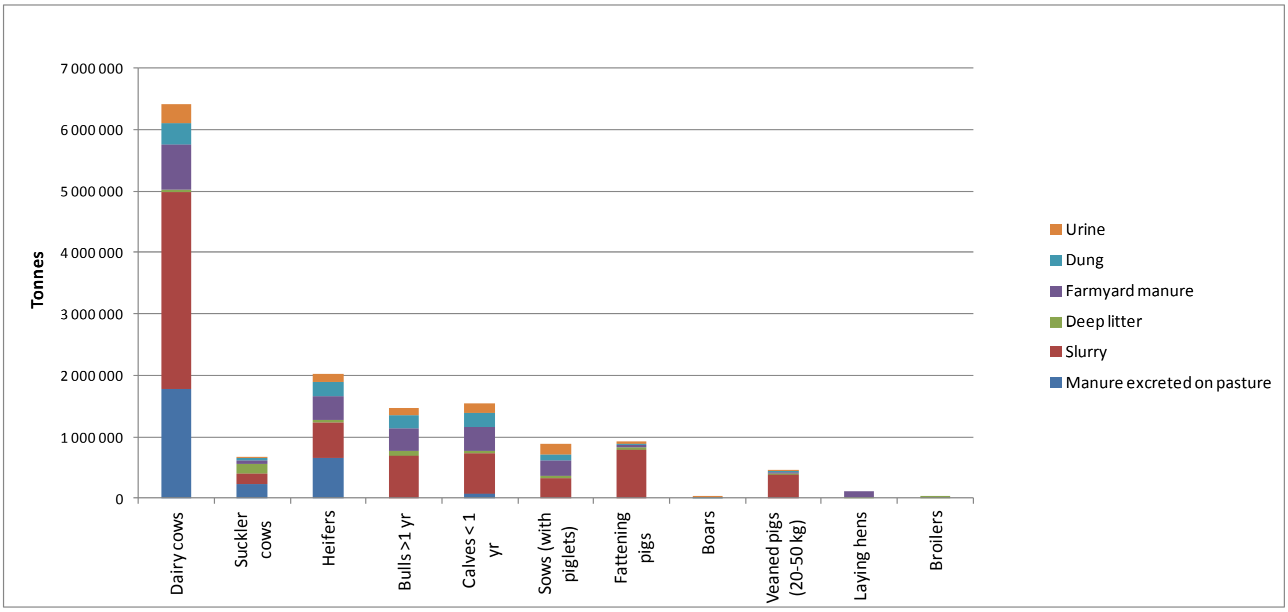


Figure 2.1. Manure volumes by animal category in Finland in 2010 (calculation provided by Juha Grönroos, SYKE, Baltic Manure WP5).

The 13.5 million tons of manure, however, provide a high potential for energy production as biogas. As reported previously (Luostarinen 2013), by including only cattle, pigs and poultry the theoretical manure energy potential as biogas amounts to 2.4-5.2 TWh/a. By excluding the smaller farms (less than 100 animals), the techno-economical potential becomes 0.85-1.8 TWh/a. This corresponds to 37% of the total manure production.

How this potential could be harnessed in practice depend among others on the location of the manure and thus the location of potential biogas plants. In the following, some ideas are presented for the Finnish situation.

2.2 Methodology

The amount of manure was calculated for each Finnish municipality using the data of animal numbers per municipality in 2010 (TIKE 2012). The amount of animals in different production line, age and species in each municipality was multiplied with manure amount coefficients based on recommendations on manure storage capacity. The decrease caused by pasturing was taken into account. The calculation method was similar to that described in Luostarinen & Grönroos (2013).

Animal locations and manure distribution was studied further with density mapping. The animal number in each Finnish farm was converted to animal units in order to compare different animal species and ages as the same unit (TIKE 2005; Ministry of Agriculture and Forestry 2007, 2008). Animal units in each farm were located to points in geographical information system, GIS, using ArcMap program. In order to visualise the animal density and regions with high manure potential, Kernel density surface was then created from points with cell size of 2500 and search radius of 10 km. The manure density map was analysed visually to see manure-rich regions which were then used to select the groups of big farms to calculate more exact number of animals. Subsequently the data was used to make a broad estimate of amount and scale of possible large-scale, manure-based biogas plants.

The amount and size of possible farm-scale biogas plants were estimated according to larger farms which were located close to each other. It was assumed that these farms could jointly build cooperative biogas plants. The possible centres for cooperative plants were based on farms that have more than 100 animal units (AU). In GIS, the over 100 AU farms were selected to represent large-scale farms. Farms with over 50 AU were selected to be medium-sized farms. The medium-sized farms were connected to neighbouring large-scale farms in every case it was found in a distance of 10 km by road. Large-scale farms without any neighbour of medium-sized farms were selected again and connected to other large-scale farms found at 10 km distance. The road distances were calculated with Finnish Road and Street dataset (The Finnish Transport Agency and ESRI Finland 2009) and ArcGIS Network Analyst OD cost matrix tool.

The amount of possible biogas plants and the number of animals producing manure for each plant was summed up to the regional level of the Centres for Economic Development, Transport and the Environment (ELY Centres). This was made because the amount of manure and other possible feedstocks were known at the ELY Centre level (Fig 2.2).

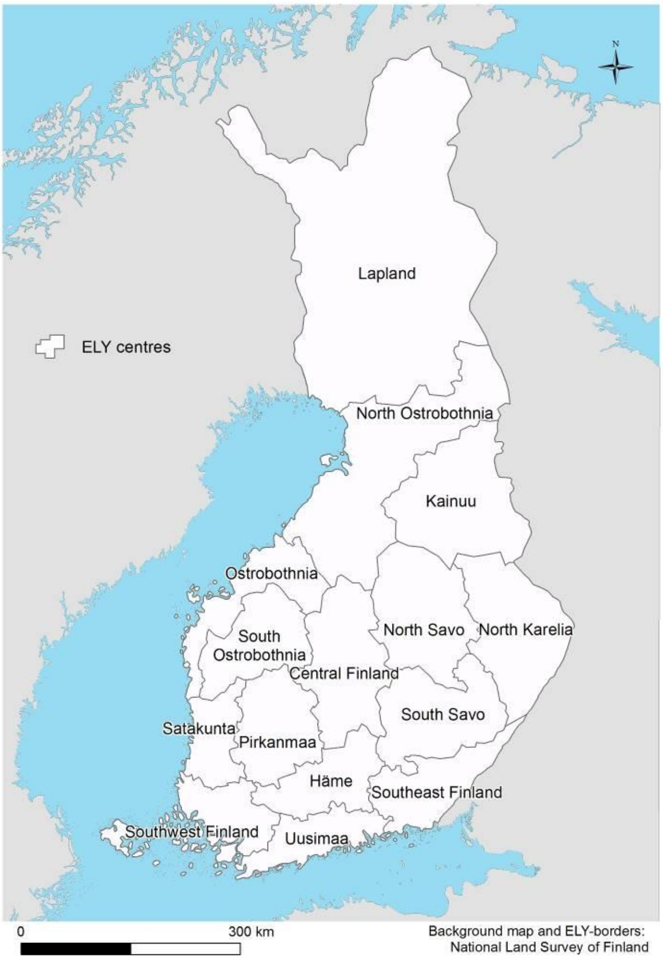


Figure 2.2. Regional Centres for Economic Development, Transport and the Environment (ELY Centres) in Finland.

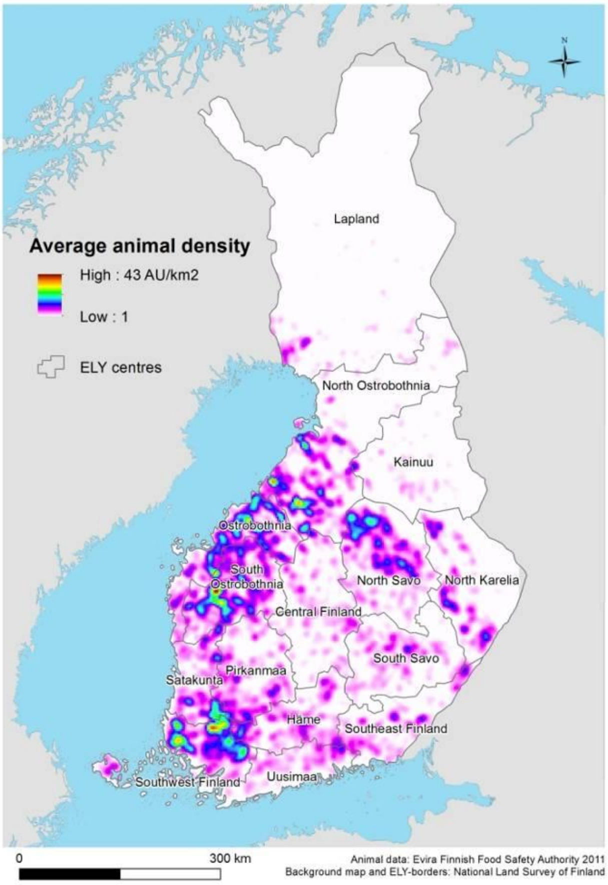
Possible biomasses for biogas production in addition to manure are e.g. biowaste, sewage sludge, agricultural by-products and wastes and energy crops. In this study, potential energy crops and agricultural by-products were taken into account as they were assumed to be the most likely co-substrates for manure. The amount of field biomass was taken from a study by Tähti & Rintala (2010) who assumed that for theoretical biogas production all Finnish set-aside land and uncultivated fields (in total 230 000 ha in 2010) could be used for energy crop production. It was also assumed that the second yield from grass and by-products from cereal production are available for biogas production. For techno-economical energy potential it was assumed that 40% of set-aside and uncultivated lands and the second grass yield could be used for biogas production. About 70% of sugar beet tops were also included into the agricultural biomass potential.

The information on investment costs for farm-scale biogas plants was estimated according to a literature research (Marttinen et al. 2013). The investment costs presented here are a rough approximate as the costs can vary based e.g. on feedstock, size of the plant and type of the plant.

2.3 Manure biogas scenario for Finland

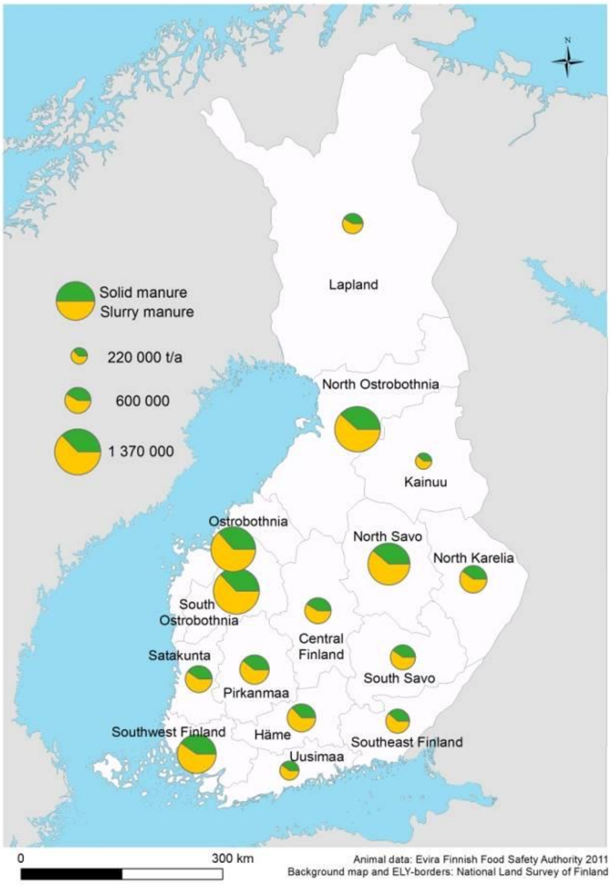
2.3.1 The location of manure and energy potential

The theoretical manure energy potential in Finland is from 2.4 to 5.2 TWh/a (Luostarinen 2013). The areas of most intensive animal density are found along the Western coast line of Finland and in North Savo (Fig. 2.3). The share of slurry is about 50 % of total manure (Fig. 2.4). When only farms with more than 100 animals are included and also the manure left on pasture is excluded, the techno-economical manure energy potential is from 0.85 to 1.78 TWh (Luostarinen 2013).



Animal data: Evira Finnish Food Safety Authority 2011
Background map and ELY-borders: National Land Survey of Finland

Figure 2.3. Distribution of cattle, pigs and poultry in Finland. Animal units are shown on Kernel density map.



Animal data: Evira Finnish Food Safety Authority 2011
Background map and ELY-borders: National Land Survey of Finland

Figure 2.4. The share of solid manure and slurry in ELY Centres in Finland.

2.3.2 Estimation of possible amount and scale of biogas plants required

The possible amount and scale of biogas plants was viewed in regional (ELY Centre) scale. When only techno-economical manure energy potential is taken into a account and the size of the biogas plant is fixed to about 1 MW, in total 173 biogas plants could be build in Finland (Table 2.1). The highest amount of potential manure biogas plants is located in the Western coast and in North Savo, where also the animal density is the highest. In Table 2.1, the size of the farms is not taken into account, only the amount of manure in each region is considered. The farm size in Finland is relatively small and in most cases building a 1 MW biogas plant would need co-operation of several farms to have enough manure for operating the plant.

Table 2.1. Theoretical and techno-economical manure energy potentials per region and the number of 1 MW biogas plants that could be built based on the techno-economical manure energy potential.

Regions	Theoretical manure energy potential (GWh/a)	Techno-economical manure energy potential (GWh/a)	Number of 1 MW biogas plants
Uusimaa	95.3	35.3	4.4
Southwest Finland	319.3	118.1	14.8
Satakunta	181.4	67.1	8.4
Häme	195.4	72.3	9.0
Pirkanmaa	217.0	80.3	10.0
Southeast Finland	154.5	57.2	7.1
South-Savo	169.9	62.9	7.9
North-Savo	422.6	156.3	19.5
North Karelia	200.4	74.2	9.3
Central Finland	180.0	66.6	8.3
South Ostrobothnia	468.0	173.2	21.6
Ostrobothnia	438.2	162.1	20.3
North Ostrobothnia	479.9	177.6	22.2
Kainuu	81.9	30.3	3.8
Lapland	118.9	44.0	5.5
Åland	25.8	9.5	1.2
Total	**3748**	**1387**	**173.4**

The amount and size of manure-based biogas plants was analysed also farm-specifically. With the GIS-based method, the amount of farms with more than 100 AU and farms with over 50 AU close to them was analysed. There are 4090 of such farms in Finland. Subsequently, the total amount of biogas plants formed by cooperative farms could be about 1050 in which case average size of each biogas plant would be 164 kW (Figure 2.5, Table 2.2). With 1050 plants in an average size of 160 kW, the implemented energy potential from manure would become 1.34 TWh/a.

Still, it must be noted that the average plant size gives just a rough approximation. There are some regions in which the farms are located very close each other and have very high amount of animals. Thus, the manure density in those regions is significantly high and biogas plants in the size of 1 - 3 MW could be formed digesting only manure. Such manure-rich areas can be found mainly in Western Finland and in North Savo.

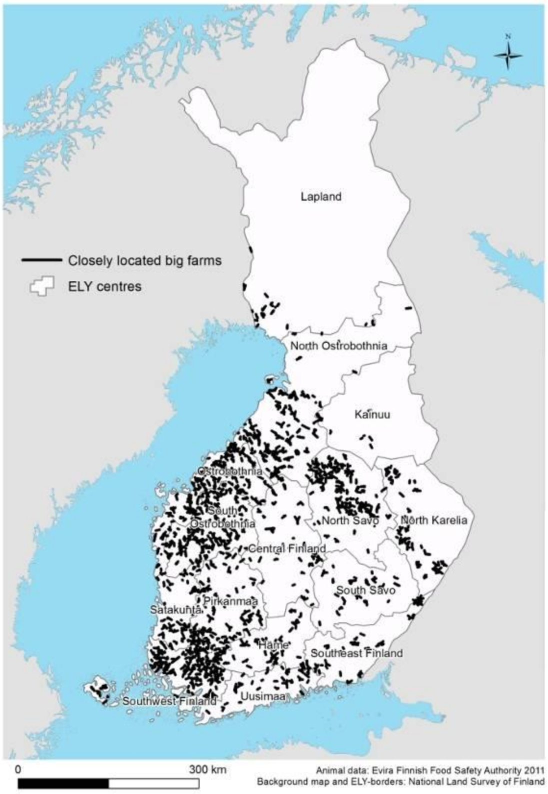


Figure 2.5. Locations of possible cooperative farms. 1054 groups of close located big farms were found.

Table 2.2. The amount of farms taken into account in the analysis, the amount of cooperative farms and the average size of the resulting possible biogas plants.

Region	Amount of large- and medium-sized farms in total	Amount of cooperative farms	The average size of biogas plants (kW)
Uusimaa	95	28	157
Southwest Finland	492	125	118
Satakunta	233	63	133
Häme	196	54	167
Pirkanmaa	224	65	154
Southeast Finland	112	30	238
South-Savo	94	27	291
North-Savo	430	107	183
North Karelia	171	46	202
Central Finland	126	36	231
South Ostrobothnia	647	173	125
Ostrobothnia	630	152	133
North Ostrobothnia	531	116	191
Kainuu	33	11	345
Lapland	53	17	324
Åland	23	6	199
Total	**4090**	**1056**	**164**

2.3.3 Estimation of possible co-substrates available for manure-based biogas plants

The amount of possible co-substrates available for manure-based biogas plants were estimated based on a literature research. Only field biomass (mainly as grass silage) was chosen even though several waste-based co-substrates are available in each region. Waste-based materials were left out as treating wastes in agricultural biogas plants increases investment costs (e.g. hygienisation requirement) and in this study only agricultural plants were considered. In some regions there is a lot of vegetable production and in those cases the by-products could be digested in biogas plants. In this study, vegetable by-products were not taken into account but it should be noted that in some farms it can form an excellent co-substrate for manure.

Adding the energy potential of the second cut of grass silage into the manure energy potential increases the total energy potential from an average of 1.4 TWh/a to 7.2 TWh/a (Fig. 2.6). The amount of 1 MW biogas plants would increase from 173 to almost 900 plants. If all the techno-economical manure and grass silage energy potential was harnessed via biogas production, the amount of e.g. 4 MW biogas plants could be about 225 (Table 2.3).

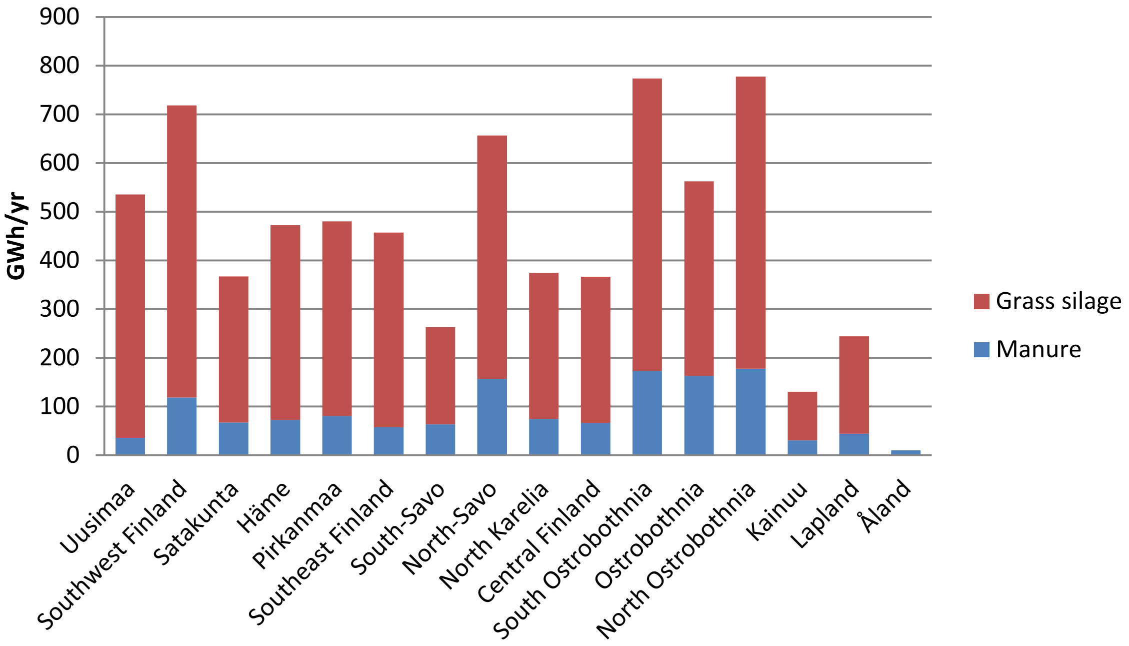


Figure 2.6. Theoretical manure and grass silage energy potential in Finland.

Table 2.3. The amount of 1 and 4 MW biogas plants that could be built based on manure and grass silage energy potential.

Region	Amount of 1 MW biogas plants	Amount of 4 MW biogas plants
Uusimaa	66.9	16.7
Southwest Finland	89.8	22.4
Satakunta	45.9	11.5
Häme	59.0	14.8
Pirkanmaa	60.0	15.0
Southeast Finland	57.1	14.3
South-Savo	32.9	8.2
North-Savo	82.0	20.5
North Karelia	46.8	11.7
Central Finland	45.8	11.5
South Ostrobothnia	96.6	24.2
Ostrobothnia	70.3	17.6
North Ostrobothnia	97.2	24.3
Kainuu	16.3	4.1
Lapland	30.5	7.6
Åland	1.2	0.3
Total	898.4	224.6

2.3.4 Investment costs and implications on employment

The investment costs of biogas plants in Finland are relatively high (Table 2.4). There are only few farm-scale biogas plants in Finland and the different technical solutions increase the difficulty of comparing the investment costs. Subsidies for investments are available as reported previously (Luostarinen et al. 2013).

Table 2.4. The average investment cost of biogas plants in Finland (Marttinen et al. 2013).

Feedstock	Amount of feedstock t/a	Investment million €
Mainly manure	15 000 – 30 000	1.3-1.7
Mainly manure	90 000	10*
Waste materials	14 000- 16 000	3.6-7**

*includes biogas upgrading unit

**includes hygienisation and pre-treatment for biowaste

As an average, investment cost of building a farm-scale biogas plant (feedstock <10 000 t/a) is about 0.5 million €. Still, savings are possible. As the price of labour is high, the farmer may get significant savings from own work at all stages. Moreover, making use of the farm's existing structures, such as existing storages, decreases the investment costs.

The total investment in biogas plants for digesting the techno-economical manure potential (about 5 million t manure/a in Finland) is about 250 million € (173 plants with 1 MW efficiency x 1.5

million euros). This investment does not include possible investments cost of hygienisation or pre-treatmens units often required when co-substrates as waste of energy crops are used as feedstock. Moreover, biogas upgrading is left out of these calculations. It is also assumed that when the amount of biogas plants is increased, the investment costs are decreased (or at least not increased) because of increasing experience and competition.

In general, getting profit from a biogas plant is difficult in Finland because of the low price of electricity and of the limited need for heat. The profitability of a farm-scale biogas plant is usually the highest if energy need in farm is high and the energy that is replaced is produced e.g. with oil. The value of recycled nutrients is currently not easily calculated or not high enough, while the reductions in emissions have no monetary value.

The effect of building biogas plants on employment depends on the feedstock and biogas technology used. As an average it can be assumed that running a biogas plant would increase the employment by 1 to 2 persons per plant. A rough estimation is that 260 new jobs can be created in a long run connected to operation of all the biogas plants digesting the Finnish techno-economical manure potential (173 plants). However, e.g. increasing silage production for energy use can have a remarkable effect on employment, depending on who performs the tasks. E.g. for silage production and straw harvest, field work is usually performed by contractors (Rasi et al. 2012). The planning and building phase of biogas plants will also increase employment and increase the knowledge requirement in the entire biogas field. This can also bring opportunities for companies to expand, to employ more personnel and to take their business also to abroad.

2.3.5 Vision for 2025

As a rough estimation, about 180 000 t manure/a is treated in biogas plants in Finland in 2013. To increase this amount to about 1.25 million t manure/a (25% of the techno-economically feasible manure) by the year 2025 on average 4 biogas plants, size of 1 MW, should be built every year during 2014-2025 (Table 2.5.). Treating 1.25 million tons of manure per year in biogas plants results in 0.3 TWh of energy produced. This 0.3 TWh/a energy production vision could also be reached by digesting 20% of the total manure produced in Western Finland (ELY centre areas North Ostrobothnia, Ostrobothnia and South Ostrobothnia) or 16% of total manure produced in Western Finland and North-Savo.

Building 43 (1 MW) biogas plants (Table 2.5.) seems like a reasonable vision when compared to the amount of large farms in Finland. In 2011, there were about 4090 large (>100 LU) or medium size (>50 LU) farms in Finland and 1056 group of farms were located closer than 10 km from each other (Table 2.2.).

If the vision for 2025 is to treat 25% of the Finnish manure in biogas plants (about 3.4 million t manure/y), it would correspond to about 0.9 TWh energy/a. To reach this target, about 10 biogas plants in the size of 1 MW (in total about 117 plants) (Table 2.5), should be built every year during 2014-2024. In Western Finland and North-Savo alone, there were about 1980 large-scale farms in 2011 indicating that if about 8% of these farms would build a 0.5 MW biogas plant, the 25% target of all manure in Finland would be achieved. Target is also achieved if about 10 % of large farms located close to each other (co-operative farms in Table 2.2.) would build 1 MW biogas plants.

Table 2.5. The 25% vision for year 2025 –an example of amount of 1 MW farms.

	25 % of techno-economical manure energy potential (GWh/a)	Amount of 1 MW biogas plants	25% of all manure energy potential (GWh/a)	Amount of 1 MW biogas plants
Uusimaa	8.8	1.1	23.8	3.0
Southwest Finland	29.5	3.7	79.8	10.0
Satakunta	16.8	2.1	45.3	5.7
Häme	18.1	2.3	48.9	6.1
Pirkanmaa	20.1	2.5	54.2	6.8
Southeast Finland	14.3	1.8	38.6	4.8
South-Savo	15.7	2.0	42.5	5.3
North-Savo	39.1	4.9	105.6	13.2
North Karelia	18.5	2.3	50.1	6.3
Central Finland	16.7	2.1	45.0	5.6
South Ostrobothnia	43.3	5.4	117.0	14.6
Ostrobothnia	40.5	5.1	109.5	13.7
North Ostrobothnia	44.4	5.5	120.0	15.0
Kainuu	7.6	0.9	20.5	2.6
Lapland	11.0	1.4	29.7	3.7
Åland	2.4	0.3	6.4	0.8
Total	346.7	43.3	937.1	117.1

In this light, neither of the visions presented above seem unrealistic. However, the biggest obstacle for increasing the amount of biogas plants in Finland is the high investment cost and difficulty of reaching profitability. Efficient incentives should be created to boost the biogas business in Finland and to increase the interest for more efficient manure treatment among farmers.

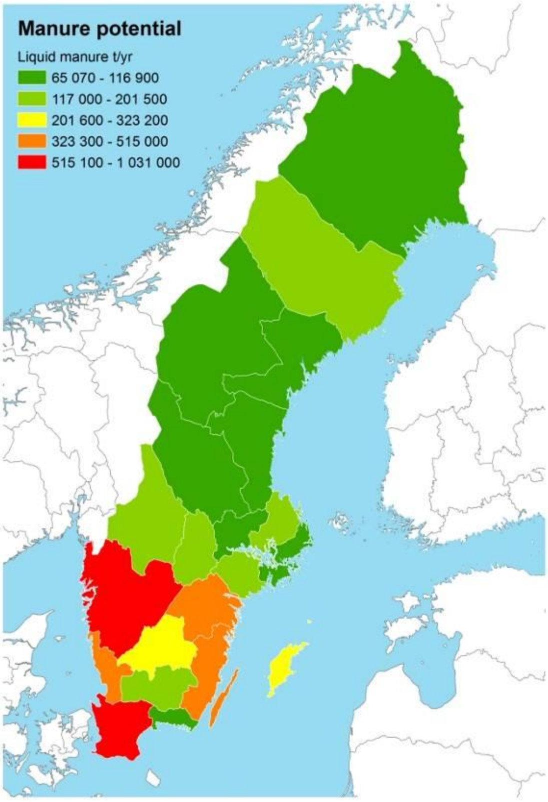
3 Sweden

Mats Edström, Johan Anderson & Eeva Lehtonen

3.1 Background

Based on the previous techno-economical calculations, 8.3 million tons of manure is potentially available for biogas production per year in Sweden (Luostarinen 2013). This corresponds to 38% of the total manure production. This calculated figure is based on 34% of all cattle manure, 81% of pig manure, 100% of poultry manure and 29% of the horse manure being techno-economically usable for biogas production. The composition of the 8.3 million tons manure is approx. 66% liquid manure from cattle and pigs, 2% solid manure from poultry and 32% solid manure from cattle, pigs and horses. The solid manure fraction is henceforth called “deep litter”, although the designation for solid manure from these animals is broader than this. The accessible techno-economical amount of manure varies a lot between the administrative provinces in Sweden (Figures 3.1 and 3.2).

With these subtractions, the techno-economical energy potential of manure biogas ranges from 1.34 to 2.78 TWh/a, which is 38% of the theoretical energy potential in Sweden. Most of the energy to be produced originates from cattle manure (54%). The contribution to the techno-economical biogas potential from pig manure is 23%, poultry manure 6% and horse manure 17%. The accessible techno-economical biogas potential from manure also varies a lot between the administrative provinces in Sweden (Figure 3.3).


Manure potential
Liquid manure t/yr
65 070 - 116 900
117 000 - 201 500
201 600 - 323 200
323 300 - 515 000
515 100 - 1 031 000

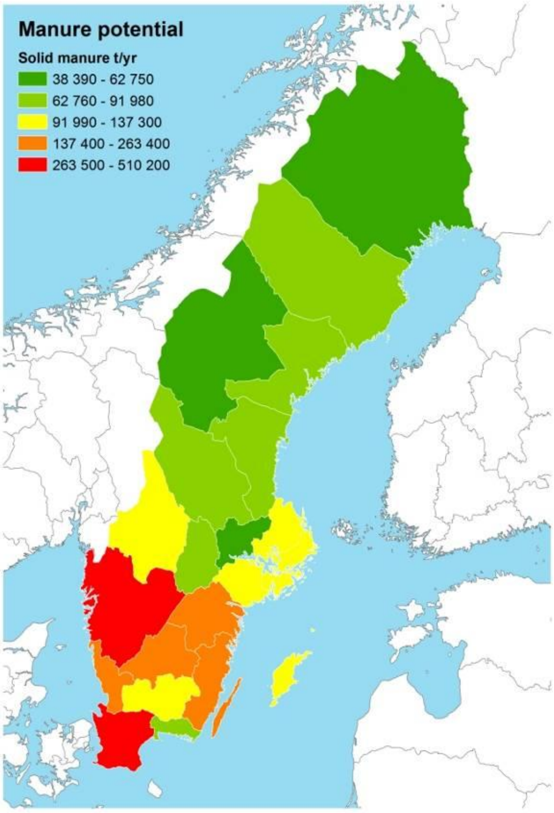

Manure potential
Solid manure t/yr
38 390 - 62 750
62 760 - 91 980
91 990 - 137 300
137 400 - 263 400
263 500 - 510 200

Figure 3.1. Techno-economical liquid manure potential for biogas production divided per administrative provinces in Sweden. The liquid manure comes from cattle and pig.

Figure 3.2. Techno-economical solid manure potential for biogas production divided per administrative provinces in Sweden. The solid manure comes from cattle, pig, poultry and horse.

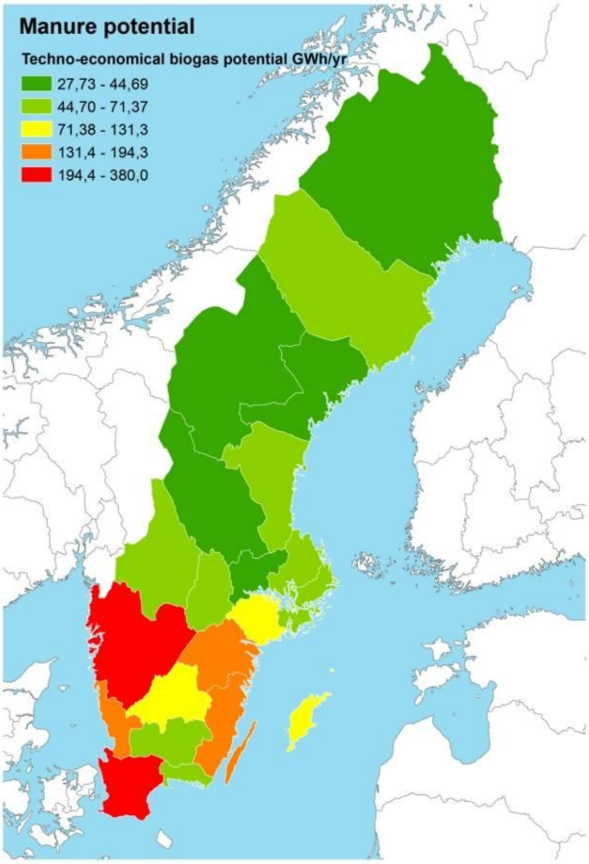


Figure 3.3. Techno-economical biogas potential divided per administrative province in Sweden. The potential includes biogas both from liquid and solid manure.

In 2012, there were approx. 40 biogas plants digesting manure in Sweden, of which approx. 25 were farm-scale plants and approx. 15 larger co-digesting plants. A rough estimation is that altogether some 350 000 tons of manure was digested per year and it was mostly liquid manure.

Most biogas plants digesting manure in Sweden are of the continuously stirred tank reactor (CSTR) type, meaning that the dry matter content in the reactor often is approx. 5% TS. Most of the feed is liquid manure but some co-substrates with higher TS-content may be used.

However, a significant amount of the techno-economical biogas potential originates from solid manure. The technology for digesting solid manure can be based on:

- Digesting in a CSTR digester.
    - A pre-disintegration step converting the deep litter into slurry is often needed before the digestion. The design of the pre-treatment step is highly dependent on the used bedding material in the barn and the amount of stones, gravel and other external

    components. In general, CSTR digestion is a well-tried technology, and it is easy to find biogas plant suppliers for it.
- Dry fermentation of solid manure (batch-operative garage reactor, plug-flow reactors, leach bed reactors).
    - Some dry fermentation plants for manure digestion have been built in Sweden, but significant problems have occurred when trying to put them in operation.

At an on-going project at JTI, co-digesting liquid cattle manure and solid manure with CSTR-technology (Mats Edström pers. com.), approximately the following manure mixtures have been tested:

- 20% chicken manure, 80% liquid cattle manure (fresh weight). Tests both in laboratory scale and at a farm-scale biogas plant with 260 m^3 digester volume. The main challenge with this mixture is the high nitrogen content in the manure mixture which can cause inhibition in the digestion resulting in unstable degradation process. After digestion, the amount of ammonia in the digestate is three times higher than in the feedstock.
- 31% deep litter manure, 69% liquid cattle manure (fresh weight). Tests at a farm-scale biogas plant with 260 m^3 digester volume. The main challenges with this mixture are 1) to design a robust and cost-effective pre-treatment step for disintegration of the fibre material in the solid manure and 2) to guarantee that the digester is continuously stirred due to increased dry matter content and fibre material causing high viscosity of the digester slurry. After digestion, the amount of ammonia in the digestate is two times higher than in the in feedstock.

3.2 Methodology

The future scenario for how to harness the calculated techno-economical manure quantities into biogas production is based on three types of biogas plants using the manure for biogas production:

1. Farm-scale manure plants. The average digester volume is assumed to be 500 m^3 (CSTR digester). Manure is the main substrate and the average amount of poultry manure is 1% and deep litter manure 36 % of the amount of digested liquid manure (Table 3.1). The plant also digests small quantities of co-substrates, see Table 3.4.
2. Large-scale manure plants. The average digester volume is assumed to be 9000 m^3 (CSTR digester). Manure is the main substrate and the average amount of poultry manure is 4.5% and deep litter manure 41.6 % of the amount of digested liquid manure (Table 3.1). The plant also digests small quantities of co-substrates, see Table 3.4.
3. Large-scale co-digestion plants. The average digester volume is assumed to be 6000 m^3 (CSTR digester). Organic waste is the main substrate (See Table 3.4). The average amount of deep litter manure is 22 % of the amount of organic waste (also including addition of diluting media) and liquid manure, see Table 3.1 and 3.4.

Table 3.1. Average digester volume, digested liquid manure and share of poultry manure and deep litter manure required for implementing techno-economical energy potential of manure in Sweden.

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	Unit
Digester volume	500	9000	6000	m^3 slurry volume

Liquid manure	4800	84 200	8100	ton/plant and year
Poultry manure	1,0	4,5	0	% of liquid manure
Deep litter manure	36.0	41.6	22.0 (x)	% of liquid manure

(x) % of liquid manure and other substrate inflow

3.3 Manure biogas scenario for Sweden

To be able digest all the techno-economical manure potential (Table 3.3), close to 900 000 m^3 digester volume (excluding volume of post-digester) is required and the biogas production will be 1.34 – 2.78 TWh/yr (Table 3.3). This digester volume could be divided into the three categories of plant described before as:

1. 700 farm scale manure plant (Table 3.2).
2. 20 large scale manure-based plants.
3. 60 large scale co-digestion plants.

Table 3.2. Number of biogas plants, digester volume and digested substrate mixture required for implementing techno-economical energy potential of manure biogas in Sweden.

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	Total	Unit
Number of plants	700	20	60	780	Biogas plants digesting manure
Digester volume, first digester	350 000	180 000	357 000 (x)	887 000	m^3 slurry volume
Liquid manure	61	30	9	100	% of techno-economical potential liquid manure
Poultry manure	31	69	0	100	% of techno-economical potential poultry manure
Deep litter manure	46	27	27	100	% of techno-economical potential deep litter manure

(x) approx. 29% of digester volume is used for manure digestion

Table 3.3. Digested manure and biogas production (only from the manure) after implementing the techno-economical energy potential of manure biogas in Sweden (Luostarinen 2013).

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	**Total**	
Liquid manure	3 362 000	1 685 000	488 000	**5 535 000**	ton/yr
Poultry manure	54 000	120 000	0	**174 000**	ton/yr
Deep litter manure	1 210 000	701 000	716 000	**2 627 000**	ton/yr
Total	**4 626 000**	**2 506 000**	**1 205 000**	**8 336 000**	ton/yr
Minimum biogas production	*0.69*	*0.42*	*0.23*	***1.34***	*TWh/yr*
Maximum biogas	*1.43*	*0.87*	*0.48*	***2.78***	*TWh/yr*

	production

3.3.1 Co-substrates

In the scenarios, also four different categories of co-substrates (i.e. non-manure-based substrates) are assumed to be digested in the three types of biogas plants as follows:

- Organic waste: Includes food waste and waste from industry and is the main substrate for the "Co-digestion plants". Total biogas potential from food waste (households, restaurants and grocery stores) in Sweden is calculated to 1.35 TWh/year and from industry 1.96 TWh/year (Linné et al. 2008).
- Grass: Includes grass from gardens, bad quality ley crop not suitable for animal feed and cultivated ley crop or other potential energy crop for biogas production. Biogas potential from garden waste in Sweden is calculated to 0.4 TWh/year (Linné et al. 2008).
- Straw: Includes straw from cereal production, lignocellulosic materials from gardens and harvested hay along roads.
- Diluting media: It is assumed that water, diluting waste like sludge from grease traps, or liquid fraction from dewatering digestate is used for pre-treatment of the organic waste before digestion.

For the "Farm-scale manure plant" and "Large-scale manure plant", the co-substrates constitute a small fraction compared to the manure (Tables 3.3 and 3.4). For "Large-scale co-digestion plant", the organic waste is the main substrate.

Table 3.4. Assumed digested co-substrate in the biogas plants defined in Table 3.2.

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	**All plants**	Unit
Organic waste	0	34 000	664 000	**698 000**	ton/yr
Grass	135 000	34 000	326 000	**494 000**	ton/yr
Straw	34 000	17 000	65 000	**116 000**	ton/yr
Diluting media	0	0	1 000 000	**1 000 000**	ton/yr

From all the co-substrates, an additional 1.33 TWh/year of biogas can be generated (Table 3.5). The main contribution comes from the organic waste with 0.8 TWh/year.

Table 3.5. Calculated biogas production from co-substrates (Table 3.4).

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	**All plants**	Unit
Organic waste	0	0.04	0.77	**0.80**	TWh/yr
Grass	0.12	0.03	0.25	**0.41**	TWh/yr
Straw	0.05	0.02	0.05	**0.12**	TWh/yr
Diluting media	0	0	0	**0**	TWh/yr
Total Co-substrate	**0.17**	**0.09**	**1.07**	**1.33**	TWh/yr

3.3.2 Investment for digestion of techno-economical manure quantities

To describe the business opportunities, only investment costs and yearly income from biogas, based on current Swedish situation, are calculated in this chapter. There are several costs connected to the operation of a biogas plant, but for simplicity, they are not shown in these economic calculations. It is not the target for this report to evaluate a complete business economy calculation for a biogas plant owner.

The investment for biogas plants digesting liquid and solid manure is based on three components (Table 3.6):

1. Basic investment for a traditional biogas plant with CSTR digesters. Farm-scale plants use the biogas for CHP-production and the large-scale and the co-digestion plants upgrade the biogas to vehicle fuel quality. For the co-digestion plant, only the investment in capacity connected to manure digestion is included!
2. Investment for pre-treatment of deep litter manure converting the solid manure into slurry and separating stones, gravel and metals.
3. Storage tanks for digestate generated from the solid manure. The assumption is made that enough of storage capacity is available for the liquid manure.

Table 3.6. Template figures for an investment of a biogas plant digesting liquid and solid manure in the Swedish manure biogas scenario. Exchange rate: 1 Euro = 8.65 SEK.

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	
1) Specific ”Basic investment”	920	690	1160	Euro/m^3 digester volume
2)”Pre-treatment” investment”	116 0000	462 000	462 000	Euro/plant
3) Specific ”storage tank” investment” (x)	30	30	30	Euro/m^3 digestate storage tank
Total specific investment	**1250**	**900**	**1290**	Euro/m^3 digester volume

(x) calculations include weight losses for manure due to produced biogas and 10 months storage capacity connected to the digestate, produced from solid manure.

The total investment in biogas plants for digesting the techno-economical manure potential is calculated to 730 Million Euro (Table 3.7). This investment does not include investment in the capacity to digest the co-substrates “Organic waste”, “Grass” and “Straw” and upgrade the biogas in “Co-digestion plants”. One should also notice that this is the total investment for digesting the total techno-economical manure quantities that have been estimated as 8.3 million tons per year in Sweden. Some capacity investment has already been implemented in Sweden, resulting in that approx. 350 000 tons of manure per year are already digested.

Table 3.7. Calculated total investment for digesting the techno- economical manure quantities.

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	**Total investment**	Unit
1) ”Basic investment”	324	125	118	**567**	million Euro
2)”Pre-treatment investment”	81	9	8	**98**	million Euro
3)”Storage tank” investment”	32	28	5	**64**	million Euro
Total investment	**436**	**162**	**132**	**730**	million Euro

3.3.3 Income and new jobs from biogas

The main source of income from biogas plants digesting manure comes from the produced biogas. The income is calculated to 159 million Euro/year (Table 3.8) and this is based on a rough estimation of the current value of biogas for CHP production and of biogas for vehicle fuel (upgraded, but not transported to a filling station) in Sweden. Excluded in this income calculation are other possibly income/reduced cost factors like:

- income from biogas generated by the co-substrates (Table 3.5)
- nutrient value of the digested manure compared to undigested manure
- gate fees for deep litter manure from horses
- value of reduced handling costs for solid manure

Table 3.8. Methane value for CHP and vehicle fuel and yearly total income for all biogas plants when the total techno-economical manure quantities are digested. Hence, this does not include income from biogas generated from the co-substrates (Table 3.5)!

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	**Total income**	Unit
Methane value	0.405	0.751	0.751	**-**	Euro/m^3 methane
Minimum income from methane	28	31	17	**77**	million Euro/year
Maximum income from methane	58	65	36	**159**	million Euro/year

A rough estimation is that 460 new jobs can be created connected to the operation of all the biogas plants in the Swedish techno-economical manure potential (Table 3.9). This also includes transportation of manure and digested manure for “Large scale manure plants” and “Co-digestion plants” but not jobs connected to plant construction and maintenance. Furthermore, it is assumed that no new jobs are created connected to manure transportation at farm-scale manure digestion.

Table 3.9. New jobs estimation for operation of biogas plants digesting the Swedish techno-economical manure and for transportation of manure.

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	Unit
Plant operation	0.4[a)]	4[b)]	1[b & c)]	New jobs/biogas plant
Manure transportation	0	2,1	0,4	New jobs/biogas plant
Plant operation	253	80	60	New jobs/category
Manure transportation	0[d)]	41[d)]	22[d)]	New jobs/category
Total new jobs	**253**	**121**	**82**	New jobs/category

a) Estimation based on: Edström et al, 2008; Brown et al, 2010.

b) Estimation based on that 4 people is needed for daily operation of biogas plant including on duty during weekend and holidays.

c) Estimation based on that 25% of work can be allocated to manure.

d) Estimation based on transport capacity 40 tons/h of liquid manure including return transport with digested manure and 30-35 tons/h of solid manure. There is also assumed, that digestion of manure at farm scale manure biogas, don't generates more transports.

3.3.4 Discussion

In the Baltic Manure scenario for Sweden only biogas plants digesting manure are accounted for. If the techno-economical manure quantities are digested together with the assumed addition of co-substrates, the total biogas production will be 2.6 – 4.1 TWh/year in which 50-68% of the biogas production comes from manure (Table 3.9). One should notice that this estimated biogas production is not including biogas from sewage waste treatment, landfills and possible biogas plants that only digest organic waste and/or energy crops without manure. Compared to an earlier investigation ordered (ER 2010:23), this study has calculated the following:

- biogas production from manure is 2-4 times higher than "Estimated future biogas production" (Table 3.9)
- biogas production from organic waste is 44% of "Estimated future biogas production" (Table 3.9)
- biogas production from straw and other by-products from cultivation is 40% of "Estimated future biogas production" (Table 3.9)
- included 0.41 TWh biogas/year contribution from "Grass / Energy crop".

This can be compared with a report from Swedish Energy Agency, Swedish Board of Agriculture and the Swedish Environmental Protection Agency that have calculated a "realistic biogas potential" for Sweden to be 14.8 TWh/year, including cultivating 10% of agricultural land for energy crops. Furthermore, an "estimated future biogas production", based on techno-economical judgments, has been calculated to 2.8 TWh/year (Table 3.9). In this judgment, the contribution from manure was 25-50% of Baltic Manure scenario for Sweden. Further on, biogas production from organic waste in this study is 44% and "straw and other by-products from cultivation" is 40% of that reported in "estimated future biogas production" (Table 3.9). Moreover, in this study, we have also included a contribution of the co-substrate "grass" adding 0.41 TWh/year. This fraction probably comes from gardens and bad quality ley crop not suitable for animal feed. If this fraction only comes from cultivated energy crop, for instance ley crop, 23 000 ha/year is needed.

The total Swedish biogas production in 2010 was 1.47 TWh/year (Statens Energimyndighet 2011b). Excluding contributions from municipal and industrial wastewater treatment plants and landfills, the biogas production from organic waste, manure and energy crop is approx. 0.44 TWh/year. Subsequently, the Baltic Manure scenario for Sweden leads to 6-9 times higher biogas production than today (including contribution from co-substrates).

Table 3.9. Biogas production for Baltic Manure scenario for Sweden including contribution from manure and co-substrates compared with an investigation ordered by the Swedish Government.

	Biogas in Baltic Manure scenario	Realistic biogas potential [1)]	Estimated future biogas production [1)]	
Manure	1.34-2.78	2.7	0.7	TWh/yr
Organic waste	0.80	1.8	1.8	TWh/yr
Grass / Energy crop	0.41	7.2	0	TWh/yr
Straw and other by-products from cultivation [2)]	0.12	3	0.3	TWh/yr
Total	**2.67-4.11**	**14.8**	**2.8**	**TWh/yr**

1) Source: ER 2010:23 including appendixes
2) Also includes tops from potato and sugar beet, bad quality potato and other by-products from crop cultivation.

Additionally, 0.73 TWh/year is upgraded to vehicle fuel quality (Statens Energimyndighet 2011b) which is the main energy use for biogas in Sweden. By reaching the Baltic Manure scenario for Sweden, the production of vehicle fuel from biogas can be increased 2.5 - 3.5 times compared to the present situation, based on that biogas farm scale plants is not used as vehicle fuel.

Based on the present situation for biogas production in Sweden (2013), to our expert judgment, it is not realistic to reach the Baltic Manure scenario for Sweden with manure energy of 2.67 – 4.11 TWh/year. The bottlenecks are both poor economy for plant owners digesting manure and the lack of reliable well-proven and cost-effective technology for solid manure digestion. Some kind of economic incentives, or legislation connected to livestock production together with R&D is needed, to reach this biogas production.

For a couple of years, there have been expectations that the Government would introduce a production related subsidy, 0.02 Euro/kWh biogas from manure, due to the several environmental benefits neglected in the current support scheme. The argumentation, however, has not been strong enough to convince the Swedish Government to enact this subsidy. The biogas market thinks this is crucial for the economy connected to manure digestion. Future argumentation can be strengthened by:

- Showing the additional positive environmental impacts when introducing effective technologies for digestion of solid manure and other lingo-cellulose-rich substrates resulting in significantly increased production of renewable energy. This will also generate a digestate with much higher content of ammonia, compared to those of the current plants. With the characteristics which allow spreading on arable land with high nutrient precision, this enables considerable reduction in mineral fertiliser used in agriculture.

- Showing that manure incentive can give a significant contribution to the entire development of the biogas market in Sweden.
- Showing the additional positive environmental impacts by investing in technology improving the degradation of manure e.g. by building post-digester and/or collection of biogas from digestate storage at the biogas plant resulting in an improved biogas production of 10-30%.

These can also be important facts in future discussions on the need to implement a new comprehensive strategy for managing manure/digested manure. The strategy should focus on producing renewable energy from manure and on increasing nutrient utilisation by crops while simultaneously reducing methane, nitrous oxide and ammonia emissions during storage and spreading on arable land.

3.3.5 Appendix 1

The accessible techno-economical amount of manure per animal type varies a lot between the administrative provinces in Sweden. This is illustrated by the GIS-illustration in figure 3.4 – 3.7.

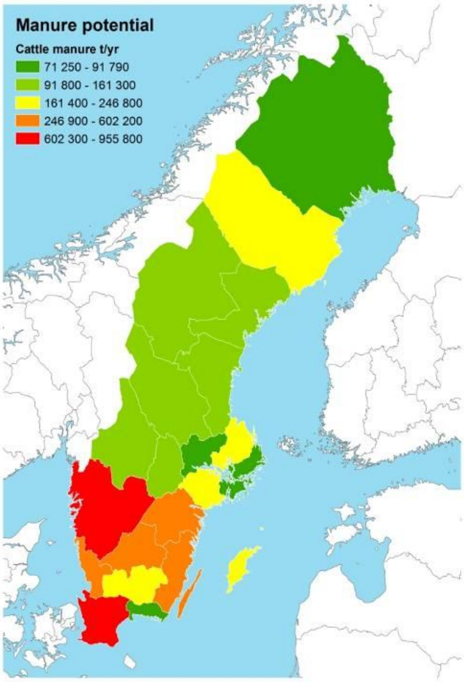


Figure 3.4. Techno-economical cattle manure potential for biogas production divided per administrative province in Sweden. The manure includes both solid and liquid manure.

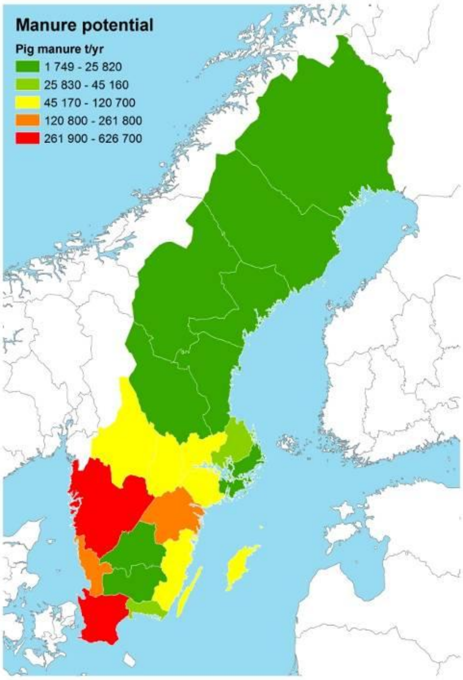


Figure 3.5. Techno-economical pig manure potential for biogas production divided per administrative province in Sweden. The manure includes both solid and liquid manure.

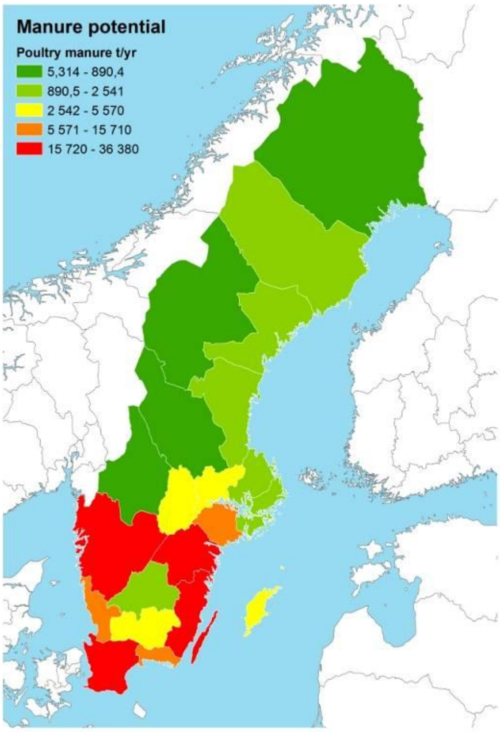


Figure 3.6. Techno-economical poultry manure potential for biogas production divided per administrative province in Sweden.

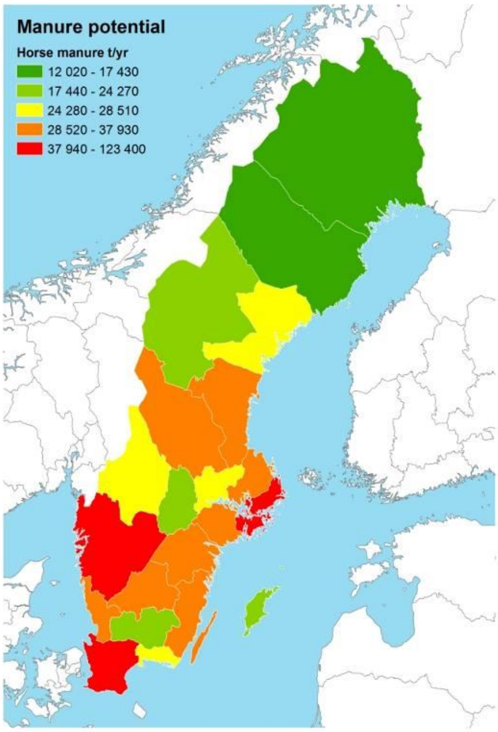


Figure 3.7. Techno-economical horse manure potential for biogas production divided per administrative province in Sweden. The manure includes both solid and liquid manure.

4 Denmark

Knud Tybirk

4.1 Background

The density of animal husbandry in Denmark is predominantly in the Western regions, in Northern, Western and Southern Jutland, and with low densities in Zealand (Figure 4.1). Northern and Western Jutland is dominated by cattle due to more sandy soils.

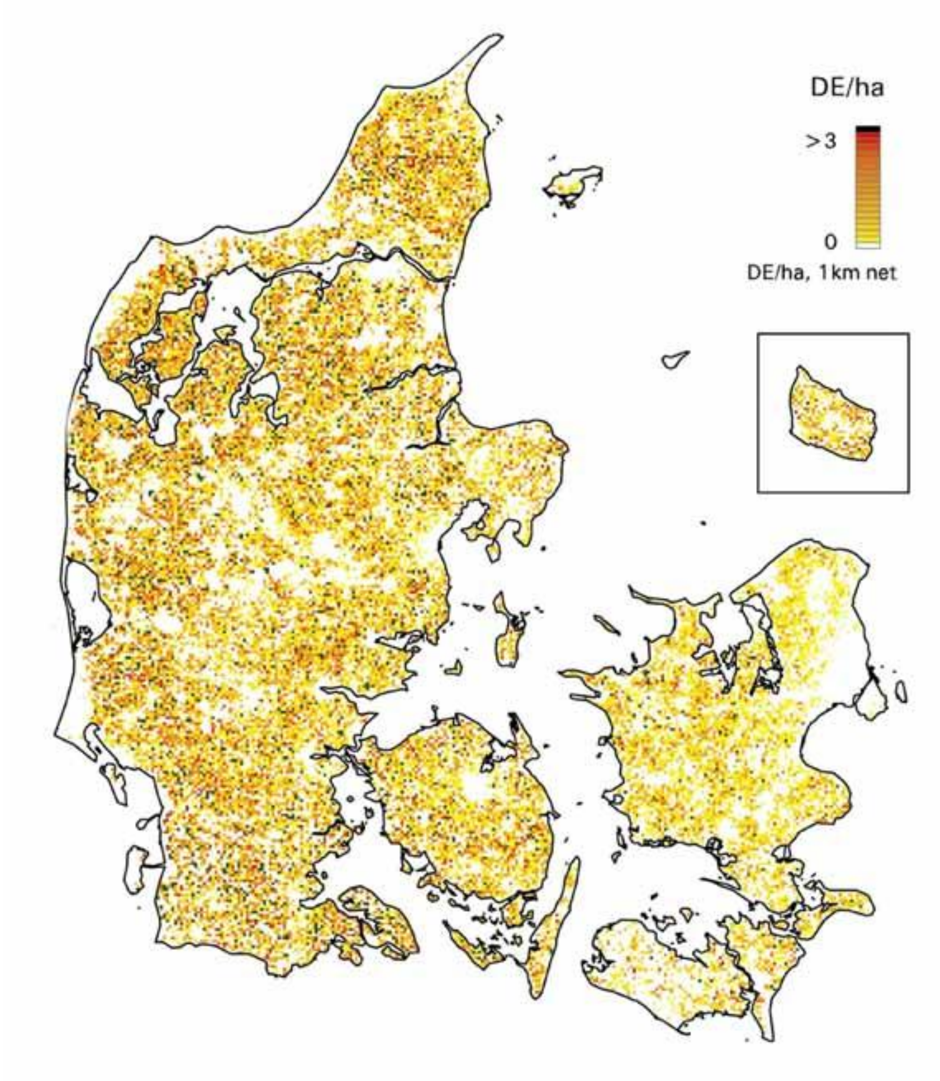


Figure 4.1. General manure density in Denmark (DE = Lifestock Unit).
Source: National Centre for Environment, University of Aarhus,
http://www2.dmu.dk/1_viden/2_Miljoe-tilstand/3_luft/4_taalegrenser/default.asp

Focusing on a smaller area as the Central Denmark Region (approx 1/3 of Danish manure), all existing biogas plants (Figure 4.2) can be shown on a map. The map shows the farm-based smaller biogas plants (triangles) and gives a visual impression of the manure resource area for the cooperative plants as circles. Theses circles do not indicate that all manure within the circle is used for biogas, rather that the circle illustrate the maximum economically viable driving distance for slurry.

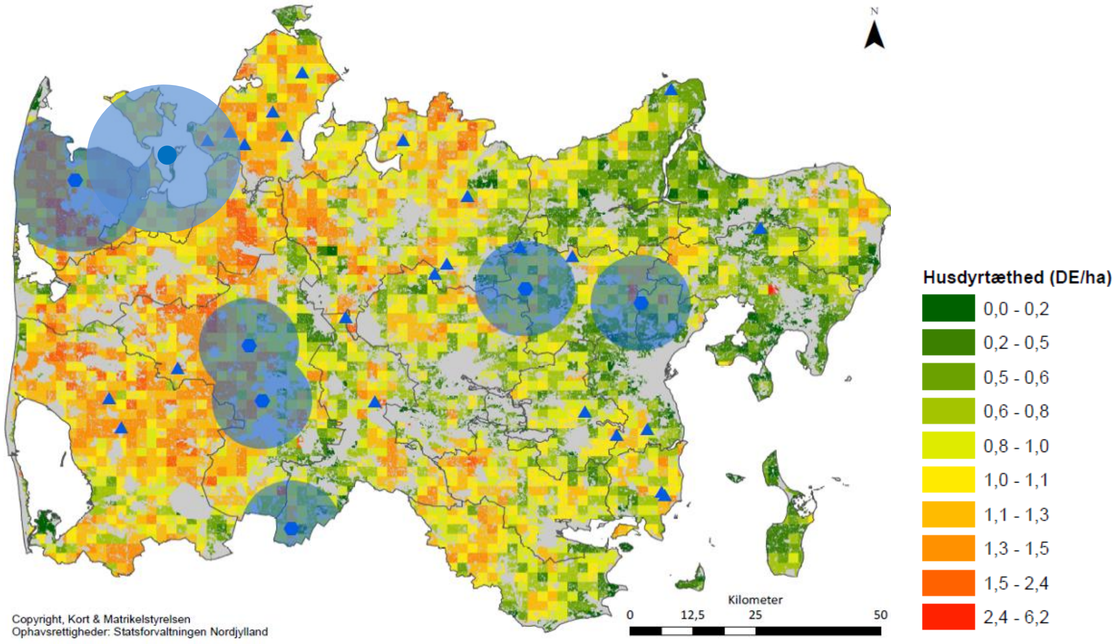


Figure 4.2. Existing biogas plants in Central Denmark region,–, farm-based plants – triangles, blue circles - cooperative plants indicating maximum economically feasible transport distance – light blue. The colours indicate the number of Livestock Units/hectare in 5x5 km grid. (Modified from Planenergi 2012).

Using this mapping, it is possible to indicate where the needs for more manure-based biogas plats are the highest, and the actual local planning is undertaken by the investors and the municipalities. This map has been used for inspiration to the 19 municipalities in Central Denmark Region to find suitable locations in dialogue with the neighbouring municipalities.

4.2 Manure biogas scenario for Denmark

Biogas is estimated to be able to cover some 60 PJ (approximately 17 TWh) or 10% of total Danish energy consumption by 2030, based on the assumption of generally decreasing energy needs (from 800 PJ today to 600 PJ by 2030). Manure in total is calculated to produce something like 20-25 PJ (5.6-6.9 TWh) out of this, the rest of the biogas will be produced from mainly agricultural and societal wastes and some energy crops (Birkmose et al 2013).

At present (2013) Denmark produces 4.1 PJ of energy from biogas (1.14 TWh) and the government has the ambition of almost ten times the amount of manure being digested, i.e. from current 5-7% of total manure being directed to biogas plant to 50% by 2020. This is a very ambitious goal that cannot realistically be reached within that time frame. In 2012, investment support (total of 260 mio DKK or almost 35 mio € – 30% of investment costs) was given to 19 biogas plants and most of these can realistically be implemented by 2016-18. These investments will probably double the amount on manure treated for biogas.

In addition, the Danish Task Force for Biogas has been in contact with another 30 biogas projects or enlargements of existing biogas plants. All these projects have in total an estimated biogas production of 10 PJ (2.8 TWh). Thus it can be optimistically foreseen by the known projects that

Denmark could reach 15 PJ (4.2 TWh) of biogas production, if all projects succeed – perhaps by 2020-22.

One scenario from the Task Force is that by 2030, 90% of all manure is used for biogas. This will require some 900 farm-scale plants and 50-100 cooperative/industrial biogas plants (depending on their size).

4.2.1 Estimation of possible co-substrates available for manure-based biogas plants

The amounts of co-substrates available on a national Danish scale are presented in Table 4.1 (Birkmose et al. 2013). It is expected that the amount of manure will decrease slightly until 2020. The deep litter and straw have the largest potentials as co-substrates for the slurry and should have first priority. In addition, mechanically separated dry fraction (fibres) from slurry should have priority, where cost-effective.

The second priority could possibly be the use of grass biomass for semi-natural grasslands and 10 meter wide water protective zones with appropriate pre-treatment (briquetting or extruding). Much focus will also be on the development of appropriate pre-treatments for increased degradation and subsequent energy yield and on separation of organic household wastes offering quite some potential as a co-substrate for manure. The current focus on separation and recycling of household wastes makes estimates of amounts in 2020 quite impossible. A new plan is expected shortly and the consequences are difficult to judge.

Table 4.1. Possible co-substrates and their amounts for manure-based biogas in Denmark in 2012 and as estimated for 2020 (Birkmose et al. 2013). Organic Household waste has not been estimated as a new resource/recycling strategy will be launced in 2013.

	2012 Tonnes DM	**Potential 2020 Tonnes DM**	**Estimated Methane production in 2020 (mio Nm3 CH4/year)**
Slurry	1 800 000	1 700 000	348
Deep litter	1 000 000	950 000	192
Solid manure	100 000	20 000	4
Straw	2 500 000-3 000 000	2 500 000-3 000 000	390-870
Catch crops	40 000	120 000	27-32
Semi-natural grass	236 000-365 000	236 000-365 000	60-90
Road side verges	15 000-70 000	15 000-70 000	3-16
Water protective zones (10 m)	70 000-140 000	70 000-140 000	15-35
Garden and park waste	108 000	130 000	12-29
Aquatic biomasses	7 000	4 500	0-1
Org. household waste	225 000	?	?

4.2.2 Investment costs for the implementation of the energy potential

Total manure amount produced in Denmark today is approximately 34 million tonnes per year, and if 5-7% is already used for biogas, that leaves 32 million tonnes unutilized.

Investment costs in Danish biogas plants vary from 33 - 66 €/ton of manure capacity annually. To reach 50% of manure being digested to biogas, another 15 million tonnes of manure should be directed to biogas plants, requiring roughly 0.5-1.0 billion € in investments. This is already an optimistic scenario – at least for 2020. Even if the subsidies would be increased drastically, this cannot be reached by 2020. One important reason for this is that the implementation of biogas plants is a rather slow process with all the planning, tendering, permitting and construction.

The scenario for 90% of total manure being treated in biogas plants will thus mean approximately 30 million tonnes of manure and total investment costs of approximately 1 -2 billion €.

The running and maintenance costs for manure-based biogas plants in Denmark are around 7-10.7€/ton of manure, and the cost per m^3 of methane produced is between 0.5-0.8€ DKK/m3 methane or 15-21€ / GJ of energy.

4.2.3 Environmental and social impacts of the scenarios

A major obstacle in Denmark for implementing the biogas scenarios is the location of larger cooperative/industrial scale biogas plants. There are always protests from neighbours, green NGO's, schools, parents etc. worried about potential smell and increased heavy traffic. These protests influence the local politicians and their decision on environmental permit and these protests have in many cases postponed the implementation process for finding the right plant location – up to 10 years!

To reach the scenario of 50% of manure being digested, the present day municipal planning is preparing for this. All Danish rural municipalities are obliged to point out suitable locations for cooperative/industrial biogas plants in the next planning cycle (will be published in 2013). This will not guarantee that the location can or will be used for biogas plants, but definitely it eases the planning process when applying for Environmental Impact Assessment and environmental permit. Investors will be asked to use these locations and the process with neighbours has already had a first phase in the ordinary municipal planning period.

Environmentally, no one has yet quantified the effects of reaching 50% of manure being treated for biogas. It can, however, be argued that if done in the environmentally optimal way, Denmark can achieve a greener agriculture (better use of nutrients) and bluer Inner Danish Waters (fjords and belts) due to reduced leaching. It is possible to contribute significantly to lowering the societal GHG emissions (1.2 kg CO_2 equivalents less emissions per m^3 of biogas produced from manure).

A limitation of energy crops as co-substrates has been set at 25% (weight based input) today (2013) and it will be decreased to 12% by 2018, strongly limiting the effects of energy crop production on landscape and induced land use changes. However, the problem is relatively limited in Denmark so far. For instance in three Danish municipalities (Randers, Norddjurs and Syddjurs; Ea Energianalyse 2012), it has been calculated that if 50% of the manure were to be treated in combination with co-substrates producing 50% of the methane, this would require either

- Increase of maize cultivated area by 3 % in these municipalities, **or**
- 17% of the straw actually being produced, being pre-treated and used for biogas, **or**

- 50% of semi-natural wetland areas of the municipalities harvested (grass silage) and pre-treated for biogas.

4.2.4 *Business impacts of the scenarios*

Apart from the social and environmental consequences, the huge investments in biogas will create employment. Each 135 000 € invested in biogas is expected to create and maintain 1.5 jobs (building, running and maintenance of biogas plants). The very simple calculation could then result in approximately 11 000 new job opportunities in Denmark, if 1 billion € is invested in biogas production from manure. These estimates do not include the production and handling of the biomass inputs and this can add/replace traditional agricultural employment by job opportunities in biomass. In comparison, the German biogas sector occupies 41 000 persons in 2010 (McGovern, pers. comm.).

5 Germany

Karola Elberg & Andrea Schüch

5.1 Background

In Germany, the share of gaseous bioenergy of the total primary energy supply of the renewable energies amounted to 15.1% or 2.9 % at the end energy demand in 2012 (BMU 2012). Despite this comparatively low contribution, the gaseous bioenergy sources play an important role in the German mix of the renewable energies. Firstly, they have a considerable development potential. Secondly, gaseous bioenergy sources can be stored and, thereby, are appropriate for the base load power supply or for mobile applications such as for the transport sector.

Over the past years, the production and utilisation of biogas has gained much importance in Germany, essentially caused by the setting of an appropriate energy-economic framework. The revision of the Renewable Energy Sources Act (Act on Granting Priority to Renewable Energy Sources - EEG) in 2004 and 2009, with additional economic incentives, encouraged investors to generate electricity out of biomass by using natural state biomass and organic waste, innovative technologies and co-generation of heat and power (combined heat and power, CHP). Due to the constantly growing amount of biogas plants in Germany (Figure 5.1), the ratio of the total energy converted out of biogas has increased considerably. By the end of 2012, there were about 7 500 running biogas plants in Germany with a complete installed electric capacity of about 3 200 MW_{el} (DBFZ 2013). Most of the plants are in the agricultural sector, primarily using renewable resources. However, considering plants fermenting by-products and wastes, a clear trend in capacity extension of existing facilities and building larger plants can be noted (Scholwin et al. 2008).

A growing trend of biogas plants is to feed biomethane into the local gas grid, after upgrading to natural gas quality. By the end of 2012, there were 120 biomethane producing plants, mostly in the renewable resource sector (DBFZ 2013). The demand for biomethane production can clearly be observed and some plants with this kind of technology are currently planned or already in course of construction (Nelles et al. 2010).

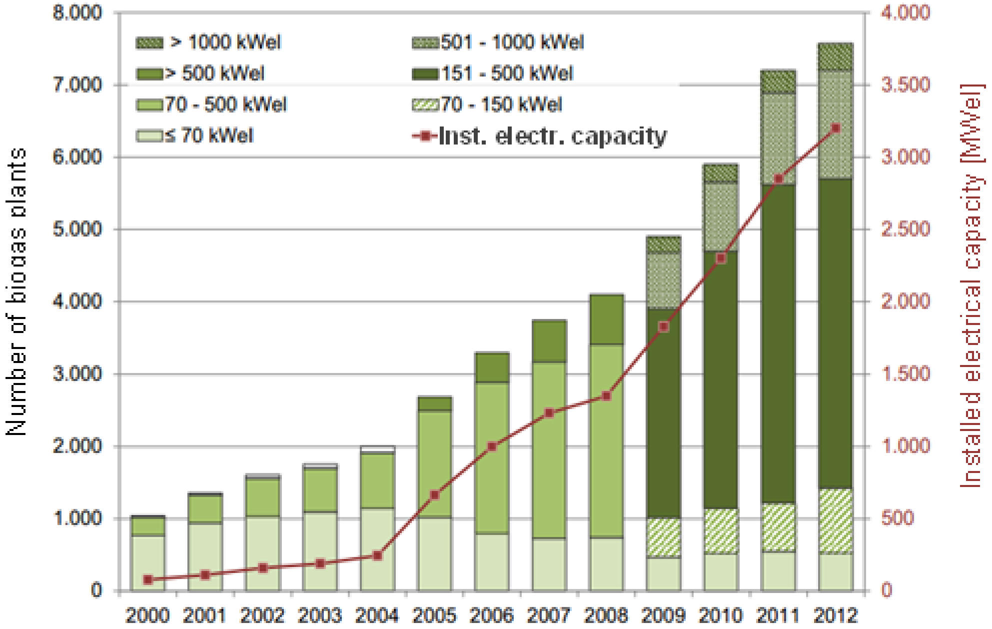


Figure 5.1. Development of the biogas sector in Germany, numbers, installed electrical capacity of the different classes and in total,
Source: DBFZ 2013 (without biomethane plants, landfill and sewage sludge gas).

Figure 5.2 shows the average installed electrical capacity of the biogas plants in the German counties. In the southern federal states of Hessen and Rheinland-Pfalz are small up to middle scale plants to be found (< 350 kW_{el}). The largest biogas plants are installed in the eastern part of Germany, as the darkest color of the figure shows. Of the two states with coastline to the Baltic Sea, in Mecklenburg-Western Pomerania the average electrical capacity of the biogas plants is 688 kW_{el} (in Brandenburg 624 kW_{el}). In Schleswig-Holstein, there are smaller biogas plants with an electrical capacity of 200 to 350 kW_{el} (DBFZ 2012 and DBFZ 2013).

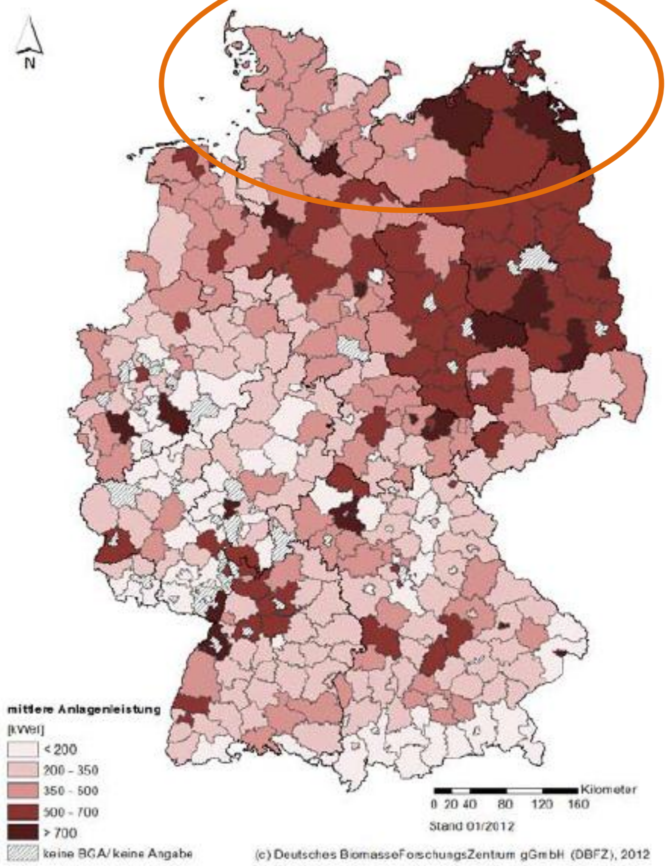


Figure 5.2. Average electrical capacity per plant in the German counties, Source: DBFZ 2012.

More important to find answers to the question how many additional biogas plants could be possible in the federal states of Mecklenburg-Western Pomerania (MV) and Schleswig-Holstein (SH) is the information on the installed biogas capacity per agricultural area. Figure 5.3 shows this relation. The highest concentration of installed biogas capacity per agricultural area is in South Germany and in Lower Saxony. In some counties the concentration is > 400 kW_{el}/ 1000 ha agricultural area. Also in some counties of MV and SH, 200 to 400 kW_{el} per 1000 ha of agricultural area is installed. In most counties the density of installed biogas capacity is between 50 and 200 kW_{el}/ 1000 ha.

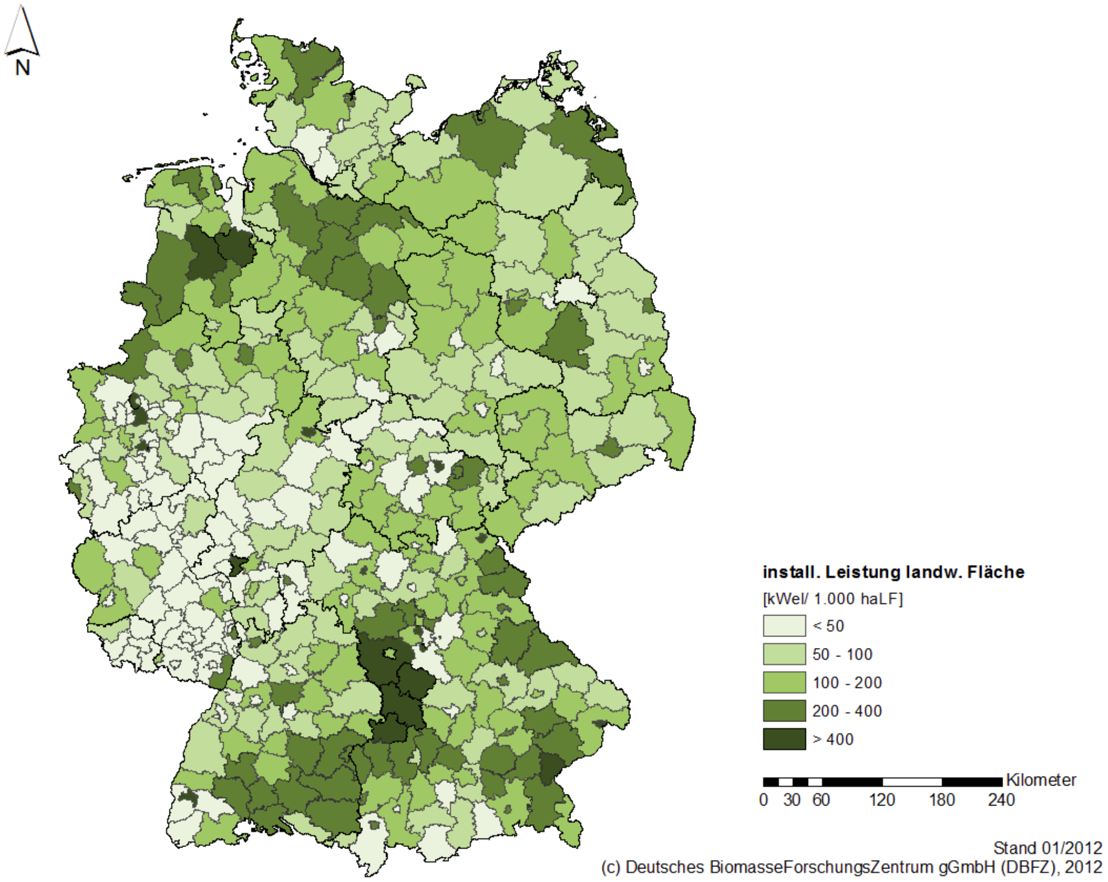


Figure 5.3. Installed electrical capacity per agricultural land in the German counties (incl. biomethane plants), Source: DBFZ 2012.

The updated EEG from 2012 has a special feed-in-tariff for small biogas plants up to 75 kW_{el} that use at least 80% manure to produce biogas to promote the utilisation of manure. Still, this measure led only to 100 new small biogas plants built until end of 2012. Most of these plants were built in Bavaria as in South Germany smaller biogas plants are more common (Figure 5.4).

In SH, most biogas plants are located in the northern part of the federal state (Figure 5.4), analogue to the biogas capacity density (Figure 5.3). The total amount of biogas plants in SH is 620. The biogas plants in MV are evenly distributed, with a total amount of 247 biogas plants. Additional to the biogas plants with mostly on-site-CHPs, in both states there are biomethane plants in operation, the largest with a capacity of 20 MW_{el} (converted) in MV (Figure 5.4).

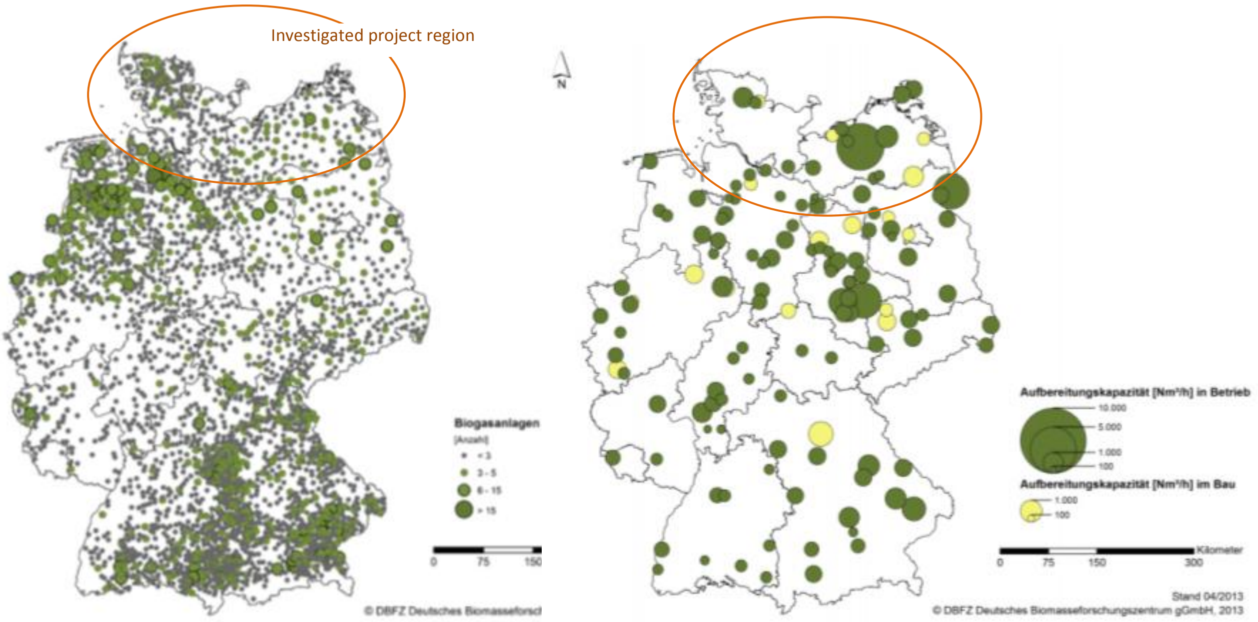


Figure 5.4. Biogas and biomethane plants in Germany, results of questionnaires in 2013, Source: DBFZ 2013.

Table 5.1. Number and installed capacity of biogas and biomethane plants in Mecklenburg-Western Pomerania and Schleswig-Holstein compared with the entire Germany, Source: DBFZ 2013, DESTATIS 2013.

Biogas	**Number of biogas plants**	**Total installed electrical capacity [MW_{el}]**	**Average installed electrical capacity per plant [kW_{el}]**
Mecklenburg-Western Pomerania	247	170.0	688
Schleswig-Holstein	620	252.5	365
Germany	*7366*	*3091.0*	*413*
Biomethane	**Number of plants**	**Total feed-in capacity [m^3 biomethane/h]**	**Average feed-in capacity per plant [m^3 biomethane/h]**
Mecklenburg-Western Pomerania	8	8965.0	1121
Schleswig-Holstein	3	1760.0	587
Germany	*120*	*71668.0*	*597*

In nearly all biogas plants in Germany maize silage is the main substrate and on average 53% (fresh matter, FM) of the entire input is from energy crops as maize, grass silage, other silages and grain. Caused by the lower energy content of manure, the proportion of energy content produced from crops is as high as 81%. Biomethane plants operate often without any manure and the average proportion of energy crops of substrates is 78% (FM) or 87% related to the energy content of the substrates. The proportion of used manure in biogas or biomethane plants is 43% (FM) and 11% (FM), respectively, as reported in Table 5.2.

Table 5.2. Composition of the used substrate input of different biogas plant categories in Germany, results of questionnaire (DBFZ 2012 and DBFZ 2013).

Installed electrical capacity [kW$_{el}$]	Proportion of the input [% FM]				*Number of answers*
	Energy crops	**Manure**	Biowaste	Industr./agri-cultural residues	
≤ 70	21	**79**	0	0	*47*
71 - 150	44	**53**	2	1	*52*
151 - 500	51	**45**	3	1	*343*
501 - 1000	60	**32**	7	1	*163*
> 1000	58	**21**	17	1	*44*

	Proportion of the input [% FM / % Energy content]				*Number of answers*
	Energy crops	**Manure**	Biowaste	Industr./agri-cultural residues	
Average biogas plants	52.8 / 81.5	**43.1 / 13.8**	3.8 / 4.2	0.3 / 0.6	*814*
Aver. biomethane plants	77.7 / 87.4	**10.7 / 2.4**	8.4 / 6.4	3.2 / 3.7	*15*

Figure 5.5 shows the proportion of the different kinds of manure which are used in the German biogas plants. The cattle slurry has the largest share with 69% (FM), followed by pig slurry with 14% (FM). In contrast, the proportion of solid cattle manure is considerably lower (7% related to the FM) and solid pig manure is seldom used. The fresh matter share of poultry manure is low with 3%, but related to the energy content higher with 13%, caused by the high energy potential.

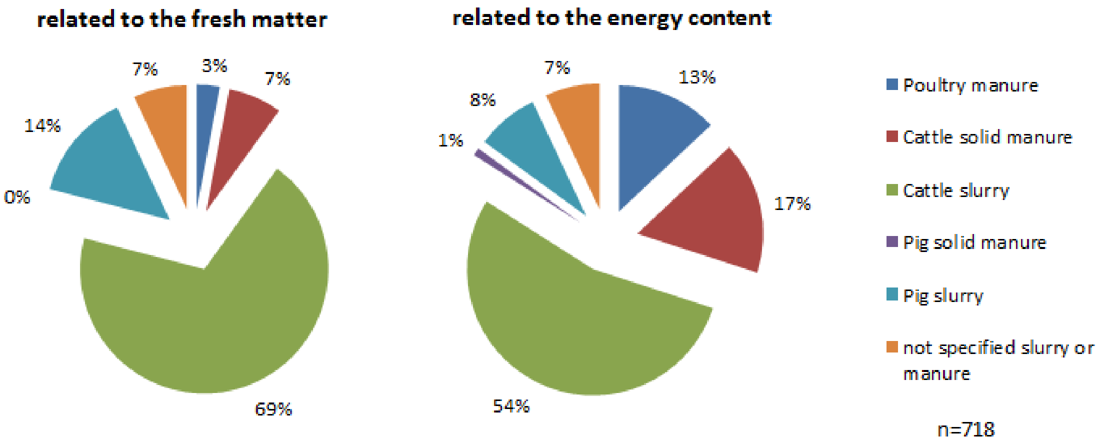


Figure 5.5. Proportion of the used manure in biogas plants (on-situ CHP), left reference: mass, right reference: energy; Source: DBFZ 2013.

A comparison of recent questionnaires (Table 5.2) has shown that more and more biogas plants use >30% manure, while the number of plants that use >50% manure decrease. The share of manure use depends on the kind of biogas or biomethane plant, but also the plant size influences the used substrate mix. It is apparent that larger biogas plants use less manure, while biogas plants with an electrical capacity of up to 150 kW$_{el}$ use predominantly manure. Biowaste is used in a low number of biogas plants mainly in plants >1000 kW_{el} (DBFZ 2012 and 2013). This means that in Germany manure is always used in combination with energy crops.

5.2 Manure biogas scenario for Germany

5.2.1 *Mapping the location of manure / energy potential*

The manure produced in the two federal states with coastline to the Baltic Sea was studied. The livestock density, as source for manure, is more than double in Schleswig-Holstein (SH, 1.07 per ha agricultural area) compared with Mecklenburg-Western Pomerania (MV, 0.4 per ha agricultural area). The proportion of the kind of kept cattle is a bit higher in SH than in MV while the share of poultry is higher in MV. The German average is 0.78 livestock units (LU) per hectare agricultural area (Bäurle and Tamásy 2012). While the LU of the counties vary in SH, the livestock density is high in nearly all of them with 1-2 LU per ha agricultural area. The livestock density is low in MV with mostly 0-0.9 LU per ha (Figure 5.6).

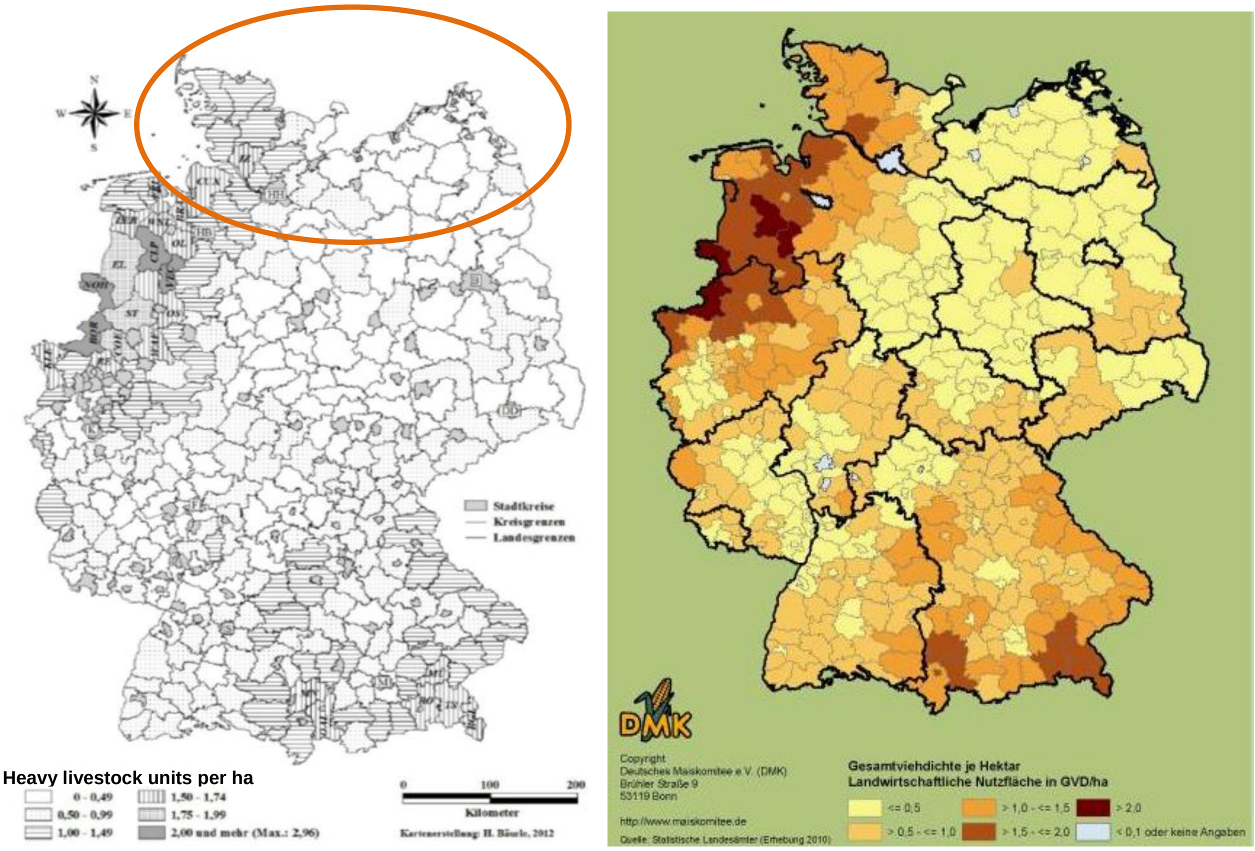


Figure 5.6. Allocation of the animal density (heavy livestock) in Germany in heavy livestock unit per hectare agricultural area in 2010, source: left: Bäurle and Tamásy 2012, right: DMK 2010.

5.2.2 *Estimation of possible co-substrates available for manure-based biogas plants*

The mainly used energy crop in Germany is maize. Caused by the high yield (per hectare) and the approved technology manure is often used together with this crop. In some regions no more maize is available for new biogas plants. The reasons for this are limited agricultural area, competition with feed and food production, especially when the grain prices are high, cross-compliance-standards and crop rotations needed. Thus, alternative biomass to maize will become more attractive. According to information from the Bauernverband (Farmer association) some biogas plants in SH use different grasses to replace the maize input. Also often used are silages from grasses, green grain, corn or grain.

A biomass with a high availability is straw. The figure 5.7 shows that especially in the north of Germany in our target regions, the potential of straw is high. Therefore, straw may become in the future a possible co-substrate for digestion of slurry without competition to fodder crops. In SH there are about 904 000 tons and in MV 1 245 000 tons of straw annually available. An industrial scale biogas plant in Zörbig already uses straw together with bagasse for biogas production.

Other possible co-substrates are organic wastes from municipalities (OFMSW) and industry or biomass from inter-cropping.

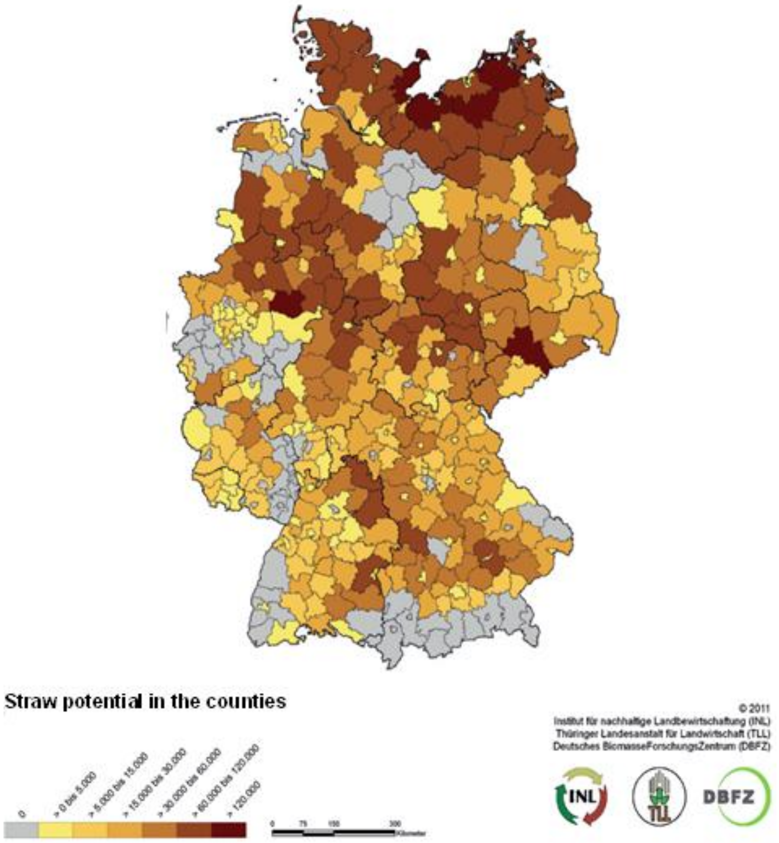


Figure 5.7. Potential of straw in the German counties, Source: DBFZ 2011.

5.2.3 Estimation of possible amount and scale of biogas plants required

Data to the status or share of manure utilisation in German biogas production is rare and unreliable. In 2011 the Biogas Association reported a share of 15%. The DBFZ reported in 2012 that in Germany 25% of the manure is used for biogas. Data to the currently amount or share of manure which is used for biogas production in the counties are not available and the present calculation is a rough estimation.

The calculation of possible new biogas plants to use the currently unutilised manure biogas potential in SH and MV base on investigations of agricultural biogas plants with an installed electrical capacity from 46 to 2128 kW_{el} (FNR 2009). In this FNR study 61 biogas plants reported the installed technology, capacity of used substrates and costs. The total manure amount in SH and MV was calculated in a previous knowledge report of WP6 ”Energy Potential of Manure in the Baltic Sea Region: Biogas Potential & Incentives and Barriers for Implementation” (German part: Elberg and Schüch February 2013). The techno-economical manure potential was considered and shown in Table 5.3 (farms with more than 100 livestock units).

Table 5.3. Total manure amount of farms with more than 100 feedstock units for different manure types in Mecklenburg-Western Pomerania (MV) and Schleswig-Holstein (SH)

MANURE TYPE	MV [t FM/a]	SH [t FM/a]	Total [t FM/a]	share of total [%]
Cow slurry	2,694,212	3,300,105	5,994,316	53.2
Cow solid manure	1,169,303	498,188	1,667,491	14.8
Pig slurry	942,652	1,841,023	2,783,675	24.7
Pig solid manure	171,764	396,930	568,694	5.0
Solid poultry manure	183,723	72,245	255,968	2.3
Total	5,161,654	6,108,491	11,270,144	100.0

One point was to find out how much substrate in total is used for the installed capacity, in order to calculate the used manure amount in the both federal states (SH and MV).

In Germany the average substrate input to biogas plants is 26 tons per installed kilowatt hour (FNR 2009). Considering the share of manure input in German biogas plants, the already used manure was calculated for SH and MV (Table 5.3). The average installed electrical capacity of biogas plants is 688 kW_{el} in MV and 365 kW_{el} in SH. The calculation bases at following data to the share of used manure (FNR 2009):

- 43% average of all biogas plants (without biomethane plants),
- 45% for 151-500 $kW_{el,}$
- 32% for 501-1000 kW_{el} installed capacity per biogas plant.

The result of this calculation is that in MV 27 to 36% of the total manure amount is used for biogas production. Caused by the high number of small farms, the techno-economical manure potential is considerably lower than the total manure amount. Therefore, in SH the already biogas used share of manure is higher and amounts to about 47%.

A specific aim/ratio to use more manure for biogas in the future has been adapted to the regional and local conditions.

Table 5.3. Calculation of the already used amount and percentage of manure for biogas production and the available manure potential of farms with more than 100 feedstock units in Mecklenburg-Western Pomerania and Schleswig-Holstein.

Region	Total installed capacity [MW_{el}]	Input total [t FM/a]	Share of manure [% FM]	Used manure [t FM/a]	Manure potential [t FM/a]	Available manure [t FM/a]	**Used manure [%]**
MV	170	4,346,941	32	1,391,021	5,161,654	3,770,633	**27**
			43	1,873,532		3,288,122	**36**
SH	253	6,456,486	43	2,782,745	6,108,491	3,325,746	**46**
			45	2,905,419		3,203,072	**48**
MV+SH					11,270,145		

*Without biomethane plants, **estimation for manure input in German biogas plants (FNR 2009): 43.1% average for all, 32% for 501-1000 kW_{el}, 45% for 151-500 kW_{el} installed capacity per biogas plant; FM = Fresh matter

Considering the available manure amount and an aim to use 30% of the total manure amount for biogas production, theoretically up to 28 new biogas in MV and none in SH has to be built (with the currently average installed biogas plant capacity) (Table 5.4). If smaller biogas plants with a higher share of manure input would be built, the needed capacity would be lower.

Table 5.4. Estimation of possible number of additional biogas plants in Mecklenburg-Western Pomerania and Schleswig-Holstein to reach 30 to 50 percent utilization rate of manure.

Possible number of biogas plants in Mecklenburg-Western Pomerania (MV)	**Manure utilisation ratio of the potential**			
	Currently 27-36%	**30%**	40%	50%
Total capacity [MW_{el}]	*170*	141-189	187-252	234-315
Total number of biogas plants*	*247*	204-275	272-367	340-458
Additional average biogas plants	***0***	**0-28**	**25-120**	**93-211**

Possible number of biogas plants in Schleswig-Holstein (SH)	**Manure utilisation ratio of the potential**			
	Currently 46-48%	**30%**	40%	50%
Total capacity [MW_{el}]	*253*	159-166	212-222	265-277
Total number of biogas plants**	*620*	436-456	582-607	272-759
Additional average biogas plants	***0***	**0**	**0**	**107-139**

* Average in MV is 688 kW_{el}; **Average in SH is 365 kW_{el}

A study of BROHMANN in 2008 showed results with a similar estimation for the counties in MV and SH (Figure 5.8). The highest potential for new biogas plants for slurry is found in the north of SH. The county with the highest potential for new manure biogas plants is the county of Ludwigslust in the western part of MV.

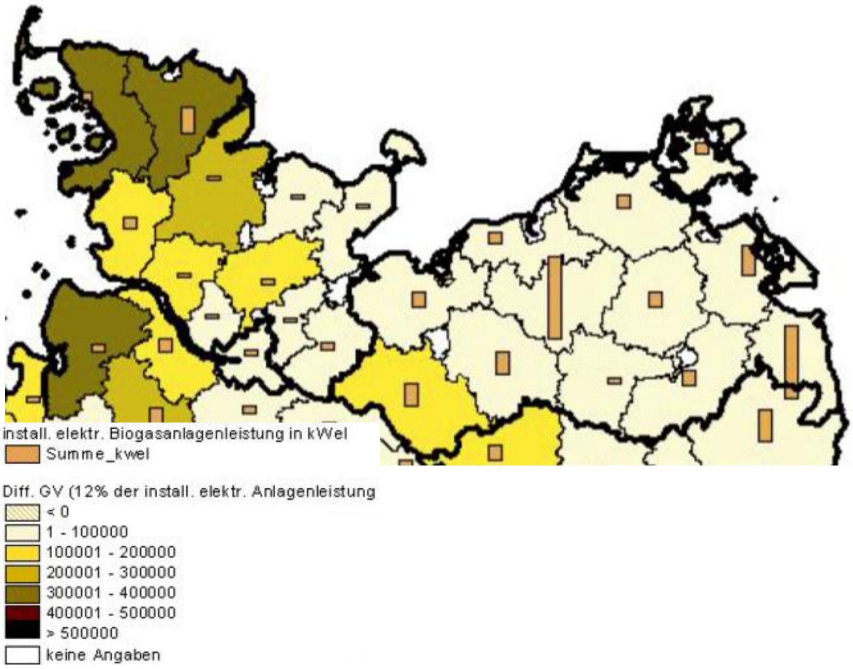


Figure 5.8. Installed electrical biogas capacity and available liquid manure potential in the counties, Source: Brohmann et al. 2008.

5.2.4 Investment costs

The investment costs for biogas plants in Germany reaches from 0.3 to 5 million Euro, the average is 1.37 million Euro. The specific cost differs from 1500 to 6000 EUR/kW$_{el.}$ (FNR 2009). The specific investment costs depends on the installed electrical capacity and decrease with increasing capacity (Figure 5.9 and 5.10).

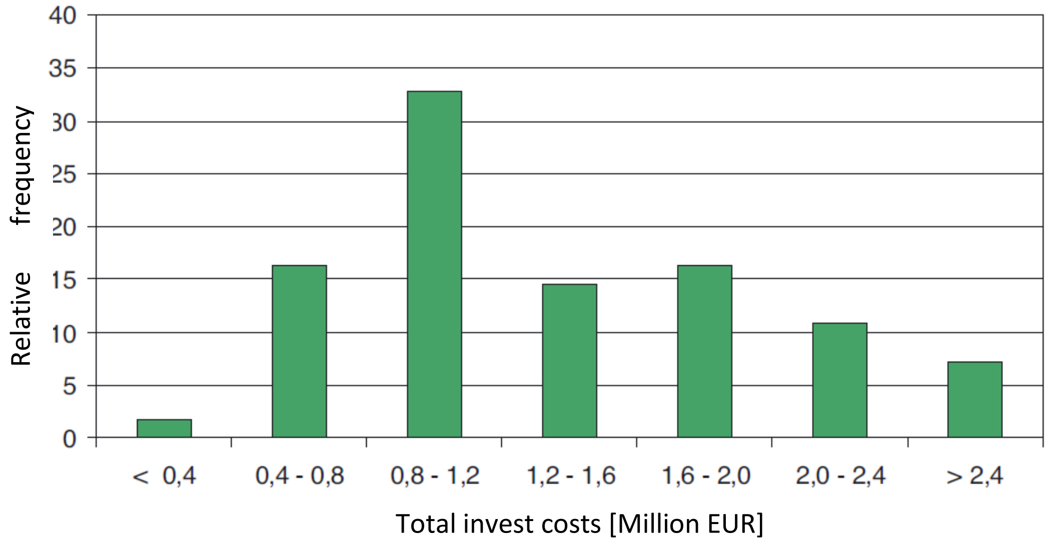


Figure 5.9. Investment costs of biogas plants in Germany, Source: FNR 2009

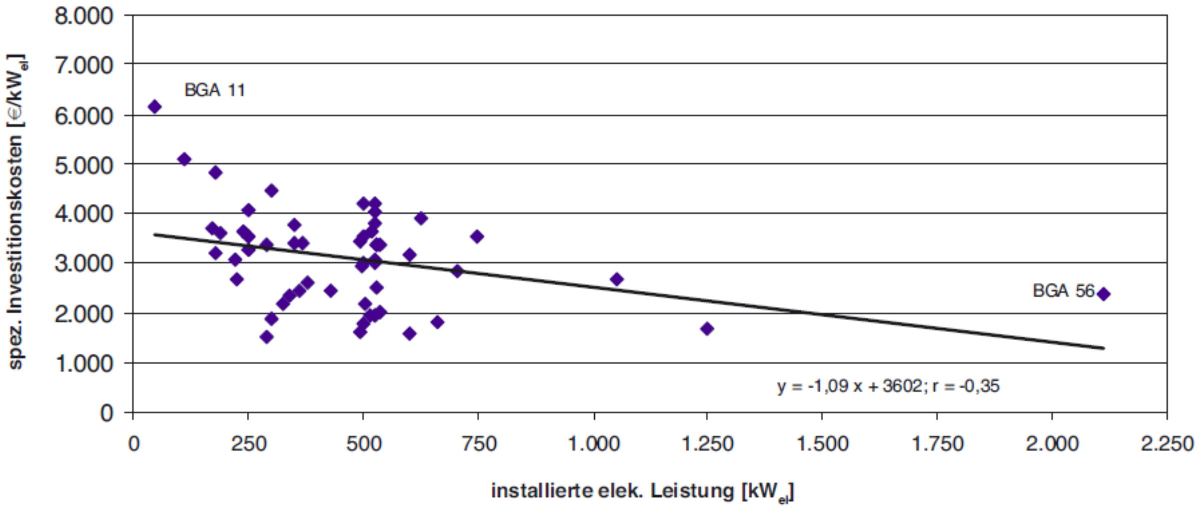


Figure 5.10. Correlation between installed electrical capacity and specific investment costs, Source: FNR 2009

Table 5.5. Investment volume to build aditional capacity to reach 30 or 50 percent manure utilisation rate (for biogas) in Schleswig-Holstein and Mecklenburg-Western Pomerania

Federal state	Average electrical capacity	Specif. investment costs	Additional biogas capacity to reach manure use of:		Investment volume to reach manure use of:	
			30%	**50%**	**30%**	**50%**
	[kW$_{el.}$]	[EUR / kW$_{el}$]	[MW$_{el}$]	[MW$_{el}$]	[Million EUR]	[Million EUR]
MV	688	2900	0-19	64-145	0 - 55	186-420
SH	365	3200	0	12-24	0	38-77

To reach a higher utilisation rate of the manure in MV and SH the share of manure in already existing plants could be increased or new biogas capacity built. To reach 30% utilization rate in SH no and in MV up to 55 Million EUR has to invest for additional plants. To reach a 50% utilisation rate in total about 200 to 500 Million EUR investment would be needed (Table 5.6).

The more economic opportunity is to use the manure in existing biogas plants. Additional technical equipment (e.g. for solid manure) or a larger storage capacity (e.g. for liquid manure) would be need for this.

5.2.5 Potential social and environmental impacts (with WP5)

In Germany especially the utilization of liquid manure is only economic together with energy crops or substrates with higher biogas potential. A higher manure utilization rate by using the state of the art is related with the use of energy crops and the cultivation of maize. If the percentage of maize cultivation area is low, as in MV, this is no problem; the environmental impact is low or not higher than for other crops.

In general the digestion of liquid manure has positive environmental impacts. In regions with a high livestock density, as in some counties of SH, the sustainable utilization of manure for fertilization is difficult. The digestion of manure together with other substrates increases the amount of liquid organic fertilizer. Also the acceptance of new biogas plants is low in these regions, because the people afraid smell, transport and environmental impacts as groundwater pollutions by nitrates. Especially the pollution of groundwater caused by to high manure and/or digestate application is reported for Lower Saxony (Höber 2013).

A solution could be a mono digestion of manure by using developed technologies, the replacement of energy plants by manure in existing plants or separation technologies and the export of digestate/manure in regions with lower livestock density.

6 Poland

Marek Ziółkowski, Ksawery Kuligowski & Andrzej Tonderski

6.1 Background

The average share of energy use from renewable energy sources was about 8% in Poland in 2009-2010. The Polish target is to reach 15% of renewable energy in final energy consumption by 2020 and further increase of this index in the subsequent years (20% in 2030; Directive 2009/28/EC of the European Parliament and of the Council). National Renewable Energy Action Plan sets a target of the share of renewable energies to be 19.13% in the electricity sector, 17.05% in the heating/cooling sector and 10.14% in the transport sector by 2020.

Energy use from biogas amounted only to 0.08% of the Polish energy pool in 2010. Biogas was produced in 28 biogas plants, 16 of them processing manure. The number of biogas plants is still growing, but to fulfil the energy potential of manure (also, waste and energy crops for co-digestion) it is vital to promote and investigate the possibilities for rapid growth of biogas sector in Poland. As especially slurry solely is too diluted and does not provide good biogas yields, attention in this Polish scenario will also be paid on co-substrates (organic waste and energy crops).

This scenario aims at showing the estimated potential for biogas production in Poland including manure, energy crops and waste as a substrate. It also covers the analysis of biogas plant investment costs and the possible locations for biogas plants in Pomorskie voivodeship.

6.2 Methodology

Technical potential of biogas production from manure in Poland was estimated using the Eurostat database. Number of heads was taken for farms larger than 100 Livestock Units (LU) and then counted for separate Polish regions, called voivodeships. Cattle manure (including manure types: slurry, FYM and faeces) was calculated for all cattle types with one exception - all male cattle were counted as bulls. Pig manure was counted for breeding sows, piglets and other pigs (0.3 LU count according to EuroStat database). Poultry manure was calculated as solid manure from broilers, laying hens and all other types of poultry. Manure amounts were counted correspondingly to Luostarinen, 2013.

The technical potential of biogas production from waste in the Polish food industry was estimated by Institute of Renewable Energy (IEO) on the basis of data from the regional waste management plans (waste code 02, Table 6.1; Wiśniewski et al. 2011). Detailed research on waste production was undertaken in the Lubelskie voivodeship based on the following assumptions. 64% of waste shown in Table 6.1 (suitable for anaerobic digestion) was classified as usable in agricultural biogas plants. Then the results were extrapolated for other voivodeships. In addition, for the calculation of technical potential it was assumed that up to 40% of waste will be available, while the rest will be used or disposed of in other ways (e.g. by incineration or composting). A group of waste defined this way, based on the percentage contribution of each waste calibrated with the data for the region of Lubelskie voivodeship, was assigned to have the average value of 170 m^3 of biogas / tonne (based on Atlas of substrates for biogas plants developed in the EU FP6 project – Agrobiogas - http://daten.ktbl.de/euagrobiogas/).

The technical potential of biogas production from energy crops in Poland is calculated assuming that there is an upper limit for using these resources based on criteria of environmental sustainability, i.e. the cultivation area is reduced to 10% of the total agricultural land in Poland. This is mainly because of the desire to reduce areas of monoculture (maize) and to prevent competition over cultivation area (intended for food purposes). The study conducted by IEO also did not take into account the area of fallow and set-aside lands, but 80% of the designated energy crops is maize due to its ease of cultivation, harvesting, maintenance and storage, and a relatively high yield per unit area (t/ha). Therefore, to simplify the analysis of the maize silage, IEO adopted the following characteristics: production per hectare 35 t, production of biogas from maize silage 185 m^3/t, methane content in biogas 52%, calorific value of methane 10 kWh/m^3. Given those assumptions, it is possible to obtain 122.5 GJ/ha of maize (Wiśniewski et al. 2011).

Table 6.1. Waste classification. Based on Wiśniewski et al. 2011.

Waste code	Type of waste	Industry branch
02 01	Waste from agriculture, horticulture, hydroponic cultivation, forestry, hunting and fishing	Agricultural waste
02 02	Waste from the preparation and processing of food products of animal origin	Poultry and meat industry
02 03	Waste from preparation and processing of Waste of plant origin, including Fruit, vegetables, cereal, edible oils, cocoa, coffee, tea waste and the waste from preparation and processing of tobacco, yeast and yeast extract production, waste from preparation and fermentation of molasses (excluding 02 07)	Potato industry Fruit & Vegetables Industry Rapeseed oil Fat industry
02 04	Waste from the sugar industry	Sugar industry
02 05	Waste from dairy industry	Dairy industry
02 06	Waste from the production of alcoholic and non-alcoholic beverages (except coffee, tea and cocoa)	Yeast, beverage and spirits industry

6.3 Manure biogas scenario for Poland

6.3.1 Overall voivodeship energy potential for agricultural biogas production

In order to estimate overall voivodeship energy potential for agricultural biogas production, the following have been investigated: total manure energy potential, total industrial organic waste energy potential and total energy crops energy potential (Figure 6.1). All of this data and additional information (manure amounts and composition) are also shown in Table 6.2.

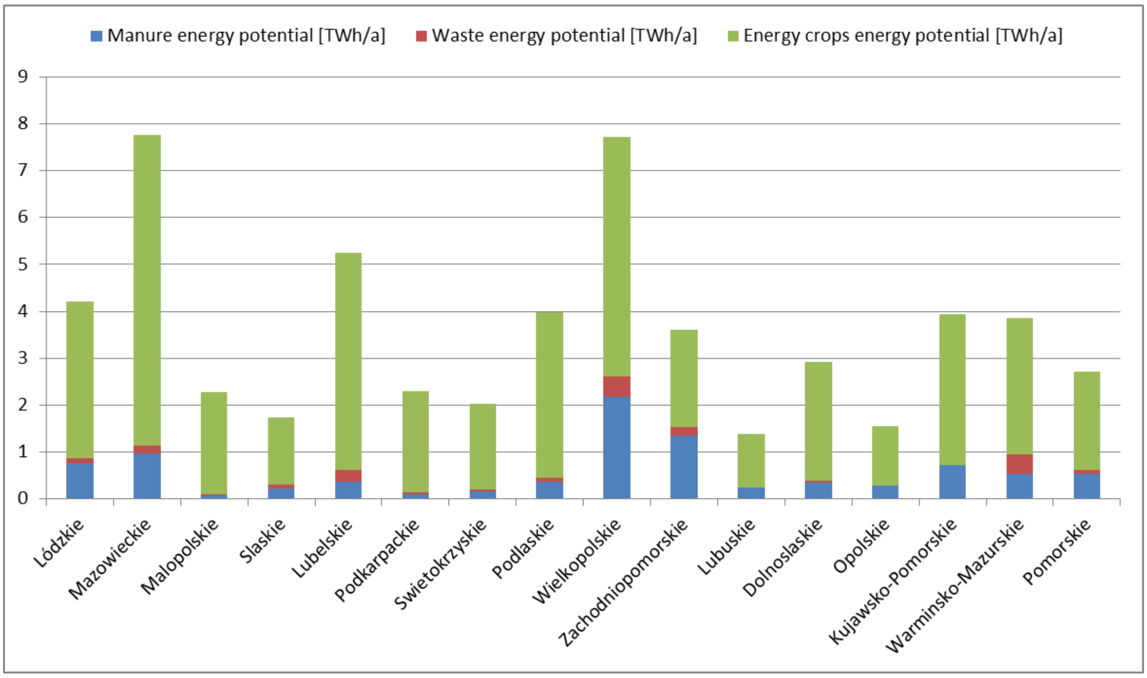


Figure 6.1. Energy potentials for voivodeships. Based on Wiśniewski et al. 2011 and own sources.

Figure 6.1 shows that the highest energy potential for biogas production from manure is in the Wielkopolskie voivodeship (2.16 TWh/a), followed by Zachodniopomorskie (1.33 TWh/a) and mazowieckie voivodeship (0.98 TWh/a). Energy crops represent the biggest potential in Mazowieckie, Wielkopolskie and Lubelskie voivodeships.

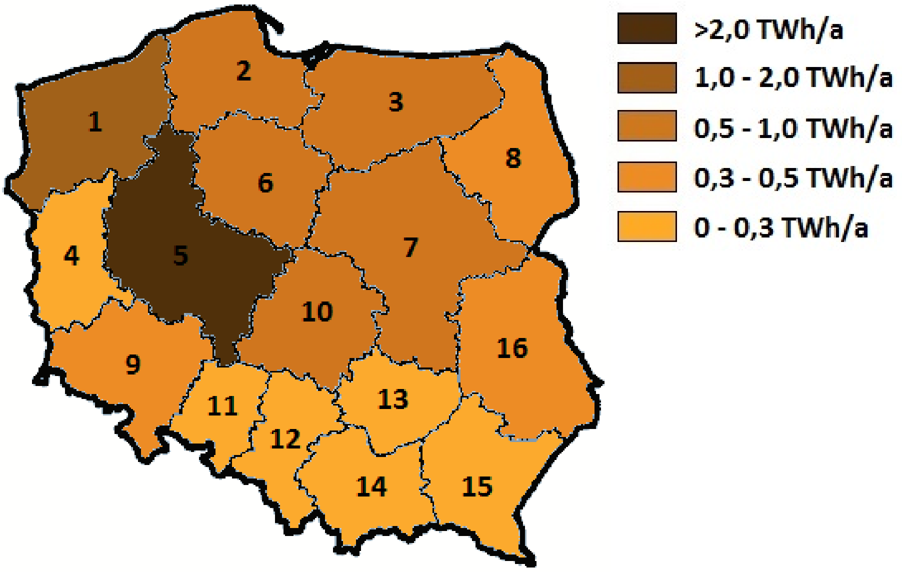


Figure 6.2. Manure energy potential. 1 – Zachodniopomorskie, 2 – Pomorskie, 3 - Warmińsko-Mazurskie, 4 – Lubuskie, 5 – Wielkopolskie, 6 – Kujawsko-Pomorskie, 7 – Mazowieckie, 8 – Podlaskie, 9 – Dolnośląskie, 10 – Łódzkie, 11 – Opolskie, 12 – Śląskie, 13 – Świętokrzyskie, 14 – Małopolskie, 15 – Podkarpackie, 16 – Lubelskie. Based on own sources.

Following Figure 6.1, the energy potential of waste is marginal, but energy crops are of great importance. The geographical distribution of manure energy potential is shown in Figure 6.2. It appears that the highest manure energy potential is present in Mid-West Poland – Wielkopolskie voivodeship, followed by North-Western Zachodniopomorskie and Central and Northern regions.

An average of around 90-95% of total manure in Poland is solid manure and only 5-10% is slurry (based on own research). The slurry is normally mixed in co-digestion with other substrates (like maize silage). Fortunately, the amount of maize silage in Poland appears to be abundant. Its energy potential also exceeds manure energy potential up to ten times.

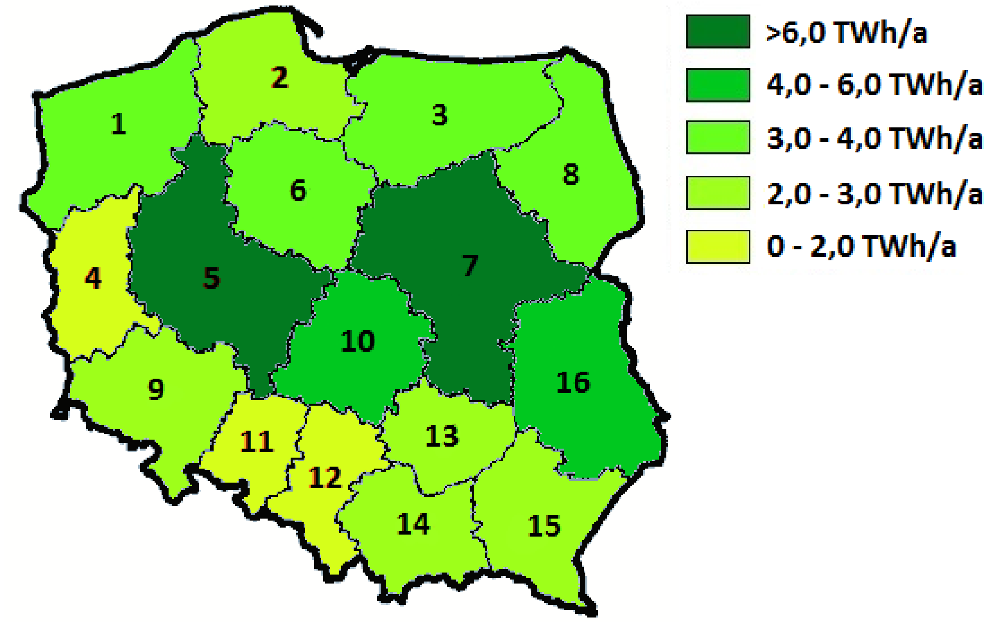


Figure 6.3. Total energy potential (manure, waste, energy crops). 1 – Zachodniopomorskie, 2 – Pomorskie, 3- Warmińsko-Mazurskie, 4 – Lubuskie, 5 – Wielkopolskie, 6 – Kujawsko-Pomorskie, 7 – Mazowieckie, 8 – Podlaskie, 9 – Dolnośląskie, 10 – Łódzkie, 11 – Opolskie, 12 – Śląskie, 13 – Świętokrzyskie, 14 – Małopolskie, 15 – Podkarpackie, 16 – Lubelskie. Based on Wiśniewski et al. 2011 and own sources.

The overall energy potential for voivodeships from all kinds of substrates (manure, waste, energy crops) is shown on Figure 6.3. Mazowieckie (7.75 TWh/a) and Wielkopolskie (7.72 TWh/a) voivodeships still have the highest energy potential, but we also observe a significant contribution of potentials in Lubelskie and Lodzkie voivodeships.

In order to make the energy potentials more comparable, it was decided to present the overall energy potentials in relation to area of voivodeships (TWh/a x Mha). The results of such comparison are shown on Figure 6.4. This showed that the highest energy potential is also in the Wielkopolskie voivodeship (2.58 TWh/a x Mha), whereas Łodzkie (2.30 TWh/a x Mha) and Kujawsko-Pomorskie (2.19 TWh/a x Mha) voivodeships also show a great potential.

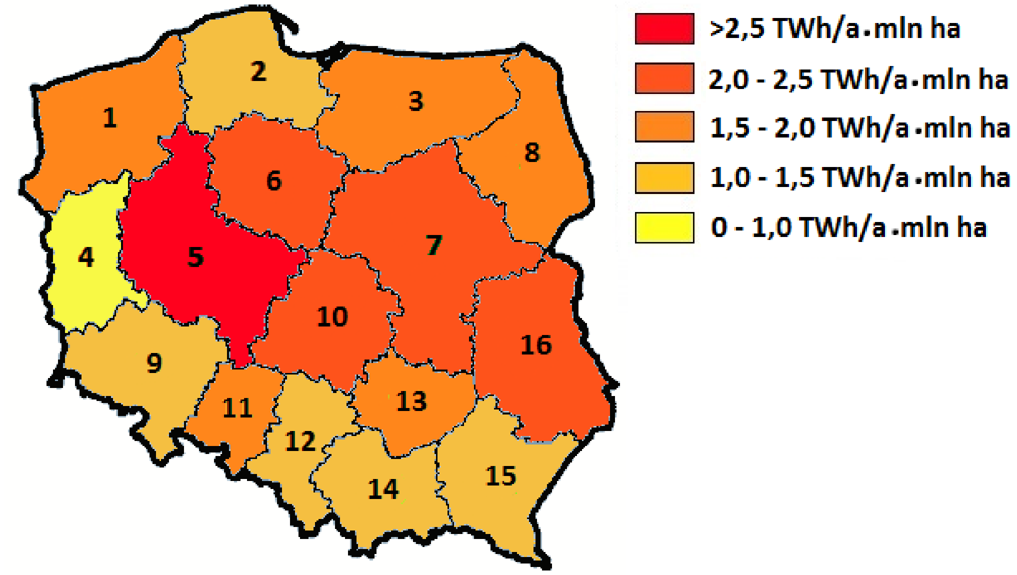


Figure 6.4. Total energy potential per million hectares. 1 – Zachodniopomorskie, 2 – Pomorskie, 3- Warmińsko-Mazurskie, 4 – Lubuskie, 5 – Wielkopolskie, 6 – Kujawsko-Pomorskie, 7 – Mazowieckie, 8 – Podlaskie, 9 –Dolnośląskie, 10 – Łódzkie, 11 – Opolskie, 12 – Śląskie, 13 – Świętokrzyskie, 14 – Małopolskie, 15 – Podkarpackie, 16 – Lubelskie. Based on Wiśniewski et al. 2011 and own sources. Unit 'mln' indicates million.

6.3.2 Estimated power of biogas plants

Table 6.2 shows the estimated electrical power of biogas plants possible to operate in a voivodeship and an average substrate structure for each voivodeship. When counting the energy potential to be used in biogas plants, it was assumed that the working time of the biogas plant is 8000 h and the electrical efficiency of the CHP engine is 35%.

Following the tendencies presented above, it is also observed (Table 6.2) that installed electrical powers of manure-based biogas plants would be the highest in Wielkopolskie, Zachodniopomorskie and Mazowieckie (when considering agricultural biogas plants). The highest potential for biogas from energy crops (to be used as co-substrates) is represented by Mazowieckie, Lubelskie, Podlaskie and Lodzkie. Counting also other biogas plants (waste-based), the conditions for biogas plants are the most favorable in Mazowieckie (Mid-East) and Wielkopolskie (Mid-West).

Table 6.2. Estimated electrical power for voivodeship for different kinds of biogas plant substrate. Based on Wiśniewski et al. 2011 and own research.

Voivodeship	**Manure (MW_{el})**	**Waste (MW_{el})**	**Energy crops (MW_{el})**	**Total (MW_{el})**
Łódzkie	33	5	146	**184**
Mazowieckie	43	7	289	**339**
Małopolskie	3	1	94	**98**
Śląskie	10	4	63	**77**
Lubelskie	16	11	203	**230**
fPodkarpackie	5	2	94	**101**
Świętokrzyskie	7	1	80	**88**
Podlaskie	16	3	155	**174**
Wielkopolskie	95	20	223	**338**
Zachodniopomorskie	58	9	91	**158**
Lubuskie	11	0	49	**60**
Dolnośląskie	15	3	111	**129**
Opolskie	12	0	56	**68**
Kujawsko-Pomorskie	31	0	141	**172**
Warmińsko-Mazurskie	23	18	128	**169**
Pomorskie	23	3	94	**120**
TOTAL	**400**	**87**	**2017**	**2504**

6.3.3 Estimated biogas plant cost

Figure 6.5 shows the ratio between the cost of a biogas plant and its power based on 21 biogas plants already existing in Poland. The average cost for 1 MW_{el} is 3.6 million euro, however, the smaller the biogas plant, the more expensive the relative investment (if counting per 1 MW_{el}). Roughly, only for biogas plants larger than 1 MW_{el} the correlation becomes more linear indicating better financial performance and faster pay-back time than for smaller plants. Based on the information gathered, the average co-financing from different sources is about 50% of investment costs in Poland. The overall investment cost for using all of Poland's energy potential thus becomes over 9 billion euro.

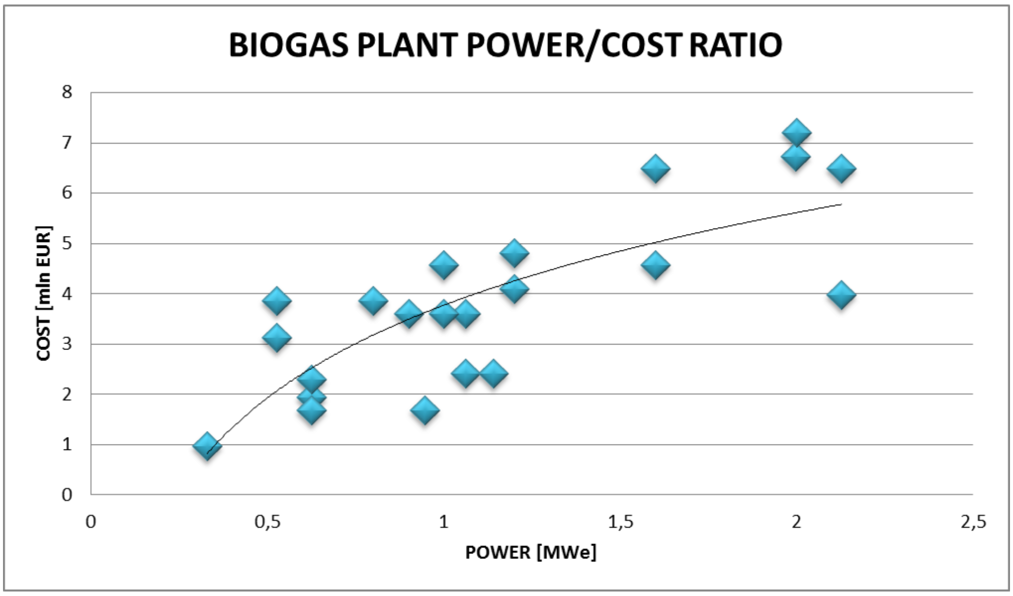


Figure 6.5. Biogas plant total investment costs as a function of its installed electrical power. Based on own research including 21 biogas plants operating in Poland. Unit 'mln' indicates millio.

6.3.4 Possible biogas plant locations for Pomorskie Voivodeship

Methodology

The mapping of possible biogas plant locations was based on several publications. Energy potential for manure-based biogas calculated by Hałuzo and Musiał (2010) used different assumptions than those used in this report, therefore, only the possible locations of biogas plants were taken into account, not the energy potentials. The authors showed 20 potential locations including 132 farms. Farms included were bigger than 60 LU, making them self-sufficient in substrates and potential for running the biogas plant on their own resources. But high investment costs and local systems for energy collection and transmission can become a barrier for such investments. Instead, possible locations presented in their report show regions predestined for centralized biogas plants (Figure 6.6). According to the authors it is possible to include also smaller farms to increase overall energy potential. A report prepared by Pomeranian Agricultural Advisory Center (2011) confirmed the findings of Hałuzo and Musiał (2010) about possible biogas plant locations (Figure 6.7).

The added value of mapping possible biogas plant locations in this report excludes all areas not suitable for such investments: natural reserves and their buffer zones, national parks and their buffer zones, landscape parks and their buffer zones, protected landscape areas, Natura 2000 areas and urban areas. That was done based on POMCERT's own research (Figure 6.8). Additionally locations of waste producers are highlighted in that map.

Results

The Figure 6.6 shows the proposed locations for centralised biogas plants utilising manure. The first number is the number of the region and circle diameter represents the area of gathering potential substrates for biogas plant. The second number is the energy production of the proposed biogas plant (in MWh/a). The authors did not exclude protected areas from the possible locations. The highest energy potential is observed in South-Western part, where industrial pig farms (mainly belonging to the company Poldanor S.A.) are widely abundant. In the Eastern part more cattle farms are present, however their potential is down to 10 times smaller than the pig farms in the South-West. It is worth noting that the range of gathering potential substrates is not proportional to the energy production, which evidences from intensive farming in the West (relatively smaller circles but with larger energy production) and extensive (dispersed) farming in the East.

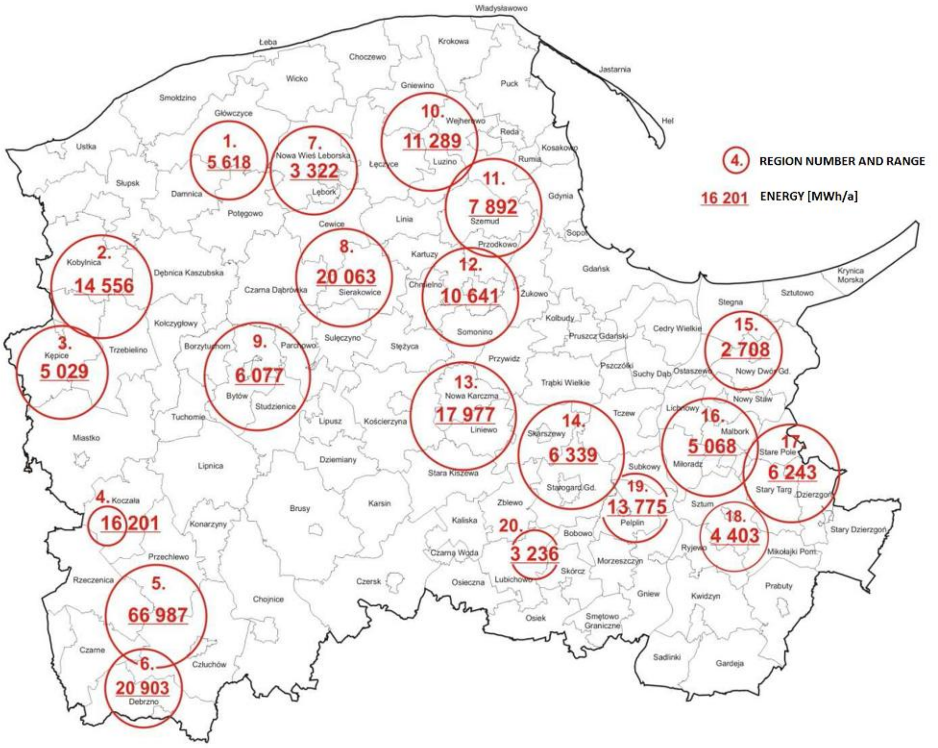


Figure 6.6. Estimated locations for centralised manure-based biogas plants in Pomorskie voivodeship (Hałuzo & Musiał 2010).

Figure 6.7 shows the overall biogas production potential from agricultural waste, municipal waste and energy crops. It was developed by Pomeranian Agricultural Advisory Center for the WAB project (Wetlands, Algae and Biogas - a Southern Baltic Sea Eutrophication Counteract Project). The figure also supports the previous study in terms of manure energy potentials, but also takes into account other waste. Thus, the total potentials are slightly higher than in Figure 6.8. It is also visible that the co-substrate structure is different (e.g. more manure in South-West and more energy crops in East). The municipal wastes (including some with post-separation of organic fraction) are located in nine locations.

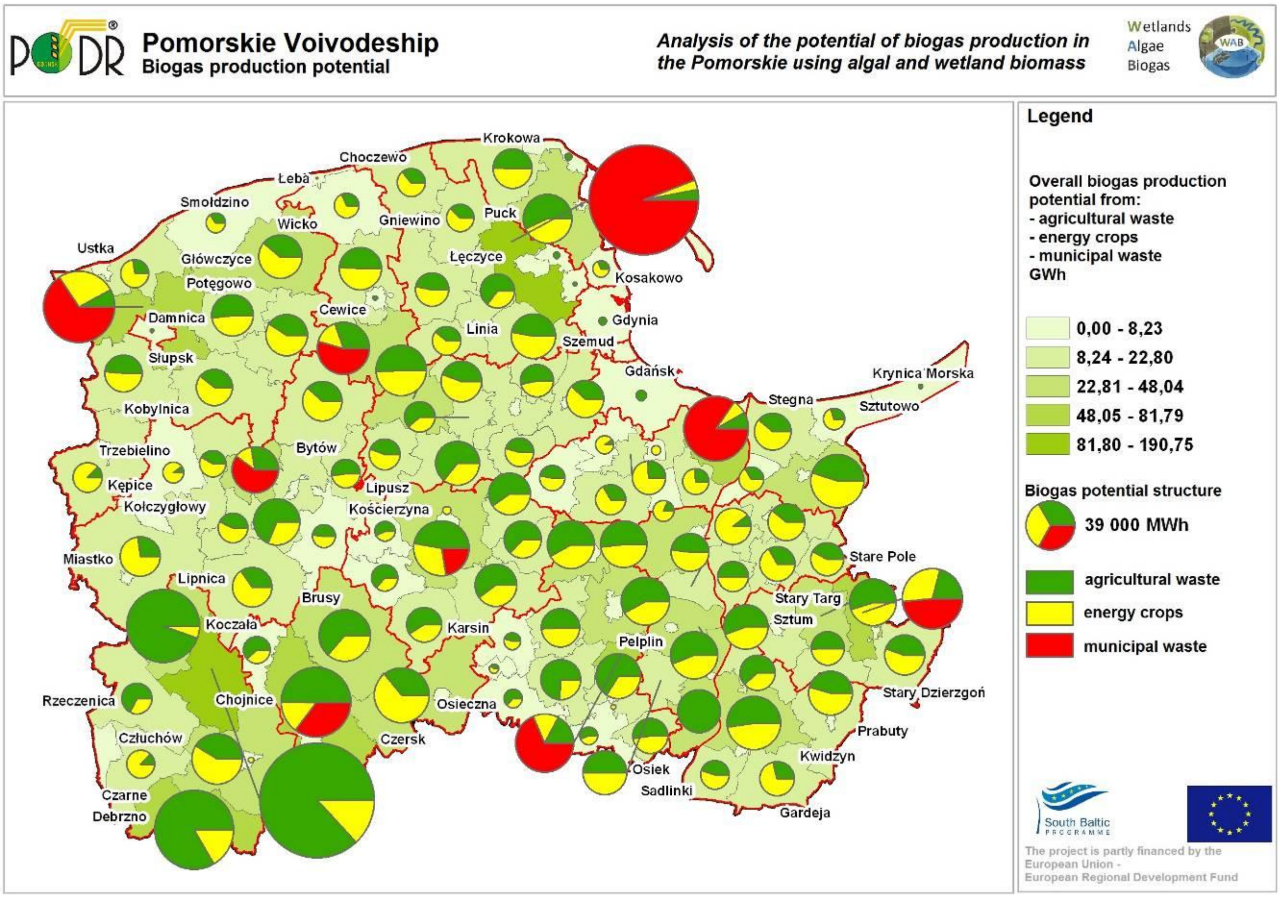


Figure 6.7. Potential of biogas production from agricultural waste, municipal waste and energetic crops (Pomeranian Agricultural Advisory Center 2011).

Figure 6.8 shows the locations of waste producers including livestock manure. In general, the locations with large amount of waste are close to urban areas. This map also excludes all areas (very light red) not suitable for such biogas investments, such as: natural reserves and their buffer zones, national parks and their buffer zones, landscape parks and their buffer zones, protected landscape areas, Natura 2000 areas and urban areas. Different organic wastes were divided into several categories, suitable as co-substrates for biogas plants (except cellulosic and wood waste). The biggest energy potential is allocated for municipal waste, presented on the map as total waste mass (including the inorganic fraction). The large waste management plant located 30 km North of Gdansk (owed by Ekodolina Sp. z o.o.) has modern mechanical segregation unit able to separate 44 000 tons of organic waste annually.

The possible biogas plant locations (regardless the waste input) in Pomorskie voivodeship, which resulted from the fusion of mentioned above studies [Wiśniewski et al. 2011; Hałuzo & Musiał 2010; Pomeranian Agricultural Advisory Center 2011] are shown on Figure 6.9. The circles denote areas (not potentials, nor electrical powers). It appears that the most suitable locations for new biogas plants are close to Three-city metropolitan area but also in South-Eastern and Northern parts.

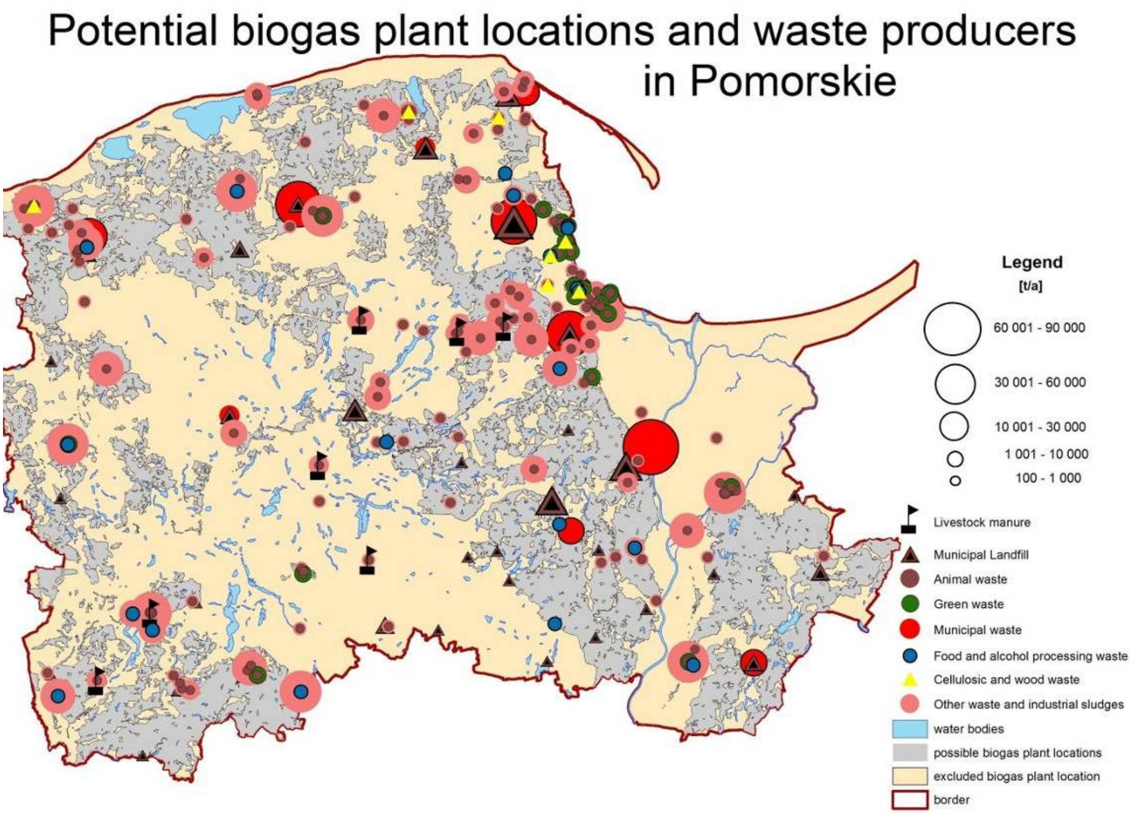


Figure 6.8. Potential biogas plant locations and waste producers in Pomorskie. Source: POMCERT.

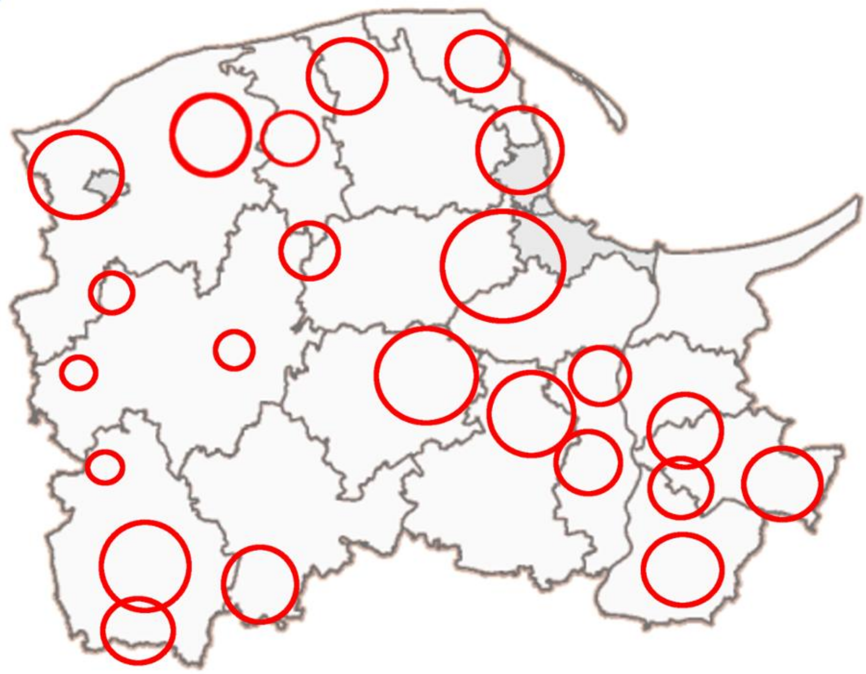


Figure 6.9. Estimated locations for centralised biogas plant locations taking into account the excluded areas. Source: POMCERT. Dark grey colour indicates the metropolitan areas of Three-city (Gdansk, Gdynia and Sopot).

6.3.5 Summary

This scenario shows the abundance of resources for utilisation in agricultural biogas plants in Poland (especially Mid-West followed by Mid-East, Central and North-West parts). The fragmented state of Polish agriculture promotes building farm-scale plants, but it appears that such investments should be centralised around the biggest farms/waste management facilities, utilising more substrate. This will certainly lower the costs for constructing and maintaining the biogas plants of electrical power amounting to 500 kW_{el} and above by not only sharing the costs, but also by adjusting the feed composition to the need of the technology applied.

The biggest issue seems to be the vast amount of solid manure in Poland (90-95% of all manure). This points up to the need for i) developing an efficient technology for processing solid manure (e.g. two-stage conversion with separate hydrolysis and methanation processes), ii) dilution of feedstock, iii) efficient pre-treatment of solid manure and/or iv) co-fermentation with slurry and/or energy crops.

Another issue is the fact that Poland is massively covered by Natural Protected Areas (such as National Parks or Natura 2000 areas) and urban areas, what results in a difficulty to find suitable locations for plants.

To optimize further the biogas plant locations requires including the road infrastructure, electricity and heat transmission networks (with CHP use) or gas grids (with biogas upgrading to biomethane). Taking into account all these necessary factors, it may appear that reaching 2000 biogas plants by 2020 would be problematic simply because of the lack of promising locations.

6.4 Vision for 2025

6.4.1 National strategies for biogas

According to Polish Ministry of Economy, the national target for biogas is to build 2000 agricultural biogas plants by 2020, roughly 1 MW biogas plant in every commune. This programme, however, does not specify the structure of substrates used in these biogas plants, thus Poland does not have yet a clear manure-to-biogas target.

National action plan for energy from renewable sources by Ministry of Economy (2010) estimates that the total electrical power from biogas from biomass will increase from nowadays (2013) 574 GWh (72 MW), i.e. 3.5% of total energy produced currently via all RES, to 4018 GWh (502 MW), i.e. 12.4% of estimated total energy produced via all RES in 2020, however this increase is not distinguished between various biomass types (i.e. manure etc.). Other study (IEO, 2011) concluded that manure contribution to planned 2000 biogas plants by 2020 will only be 40% (mass wise) and 20% (energy wise).

6.4.2 Geographical probability to meet the vision

In previous chapter (Fig. 6.1, Fig. 6.2), it was observed that the highest manure energy potential is in central and western Poland. Studies of Institute of Renewable Energy covering farms viable for biogas production (cattle > 100, pigs > 500 animals, poultry > 5000 animals) also support the fact that potential biogas locations would be privileged in these areas.

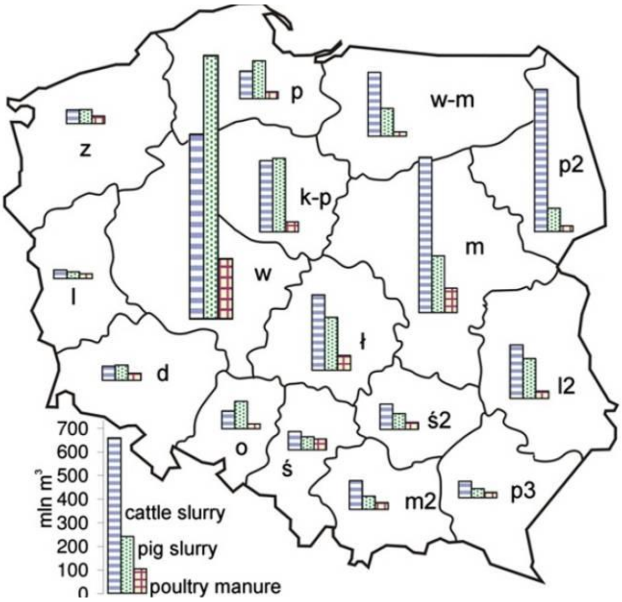


Figure 6.10. Theoretical biogas potential in Poland divided into biogas from cattle slurry, pig slurry and poultry manure for different voivodeships. Based on Iglinski et al. (2012): animal heads from Central Statistic Office, biogas potential calculated based on LU (0.8 cattle, 0.2 pig, 0.004 poultry) exretion factors for each animal.

This is somehow supported by Iglinski et al. (2012; Fig. 6.10), where high potential (also techno-economical) indicates that possible slurry-based biogas plants should be located in the central parts of Poland. Figure 6.11 shows the theoretical biogas potential, for pig and cattle, only slurry-based, as this the main substrate of nowadays conventional fermentation technology (CSTR). Solid manure, much more abundant in Polish animal farming, is not included here.

Figure 6.11 supports earlier statement that the greatest manure-based biogas potential is in central (1.5-2.2 M tonnes/ year), central-western (4.2-6.6 M tonnes/year), central-eastern and north-western (2.2-4.2 M tonnes/year) parts of Poland, with pig manure being the most abundant. Southern and south-western voivodeships are characterized by manure amounts lower than 1 M tonnes/ year.

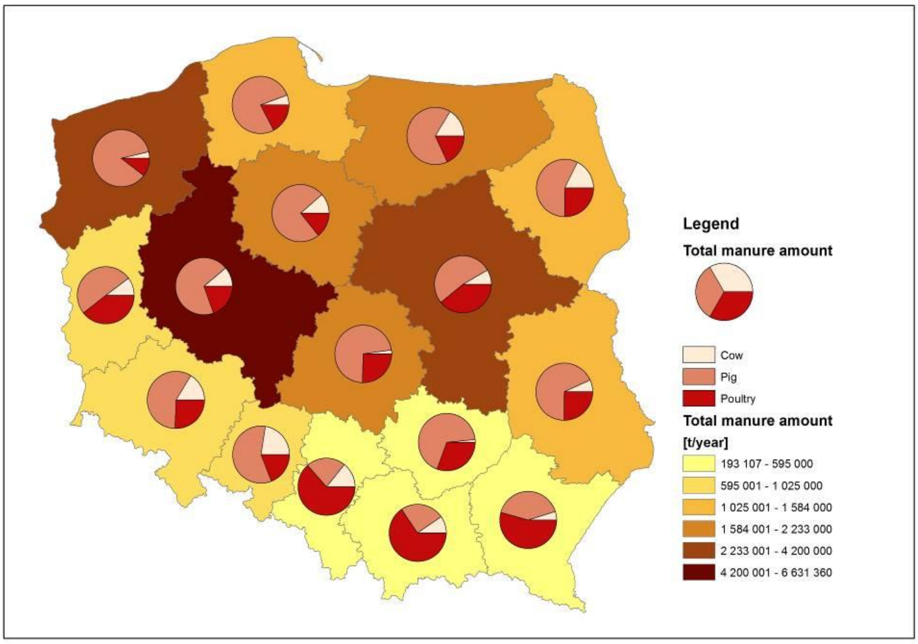


Figure 6.11. Geographical distribution of total manure on farms > 100 LU with division between cow, pig and poultry for each voivodeshop. Source: POMCERT based on Eurostat.

6.4.3 The role of solid manure in meeting the vision

In fact meeting the hypothetic target of 25% manure to biogas by 2025, especially for Polish conditions, is very challenging. First of all, according to previous study (Luostarinen 2013), in Poland less than half of total manure amount is available for biogas production (ca. 28.1 out of almost 70 million tonnes). Secondly, most of this amount is solid manure (94.2%), which can only be digested as a co-substrate in for example co-digestion with slurry, if using currently available wet fermentation technology based on CSTR. Table 6.3 shows calculations for the hypothetic, future scenario, where all Polish pig and cow slurry is co-digested with appropriate amounts of solid manure. In spite of using 100% slurry, only 6.5% of cow solid manure and 1.7% pig solid manure can be directed into biogas plants giving in total only **7.4%** of total manure used in the biogas production (all slurry + solid manure additions). If referring to total manure amount in Poland (including farms < 100 LU), this percentage would be less than 3.

Such amount of manure presented in this scenario would give ca. 70.7 MW of power annually (565 GWh), which according to the national target for total energy from biomass based biogas explained earlier (502 MW) is only ca. 14.1%. Hopefully other substrates, including waste and energy crops could fulfil the planned levels. This calculation clearly shows that manure, in opposition to cultivated energy crops in Poland, should be more in focus, when planning biogas investments. Unfortunately many new investments will use traditional maize silage, often grown only for biogas purposes in a long run leading to induced land use changes.

Table 6.3. Calculated manure amounts and resulting techno-economic potential for the Scenario: all Polish slurry (both cow and pig) co-digestion with solid manure (both cow and pig) additions. Manure amounts, reference data for calculation of percentages are equivalent for farms > 100 LU, thus viable for biogas production. They do not represent the total manure amounts. Source data and calculations methodology in Luostarinen 2013.

Manure digestion/ co-digestion scenario	Manure	Unit	% of total liquid m. in PL[2]
All cow slurry to biogas	517 720	t/a	100
All pig slurry to biogas	1 106 345	t/a	100
liquid: solid ratio based on required C:N and TS[1]	3.65	NA	% of total solid m. in PL[2]
Desired cow solid manure as co-substrate	141 841	t/a	6.4
Desired pig solid manure as co-substrate	303 108	t/a	1.7
			% of total manure in PL[2]
Total cow manure to biogas (all slurry + solid addition)	659 561	t/a	2.3
Total pig manure to biogas (all slurry + solid addition)	1 409 453	t/a	5.0
Total manure to biogas	**2 069 014**	**t/a**	**7.4**
Techno-economic biogas potential from	Power		% of total potential[2]
All cow slurry	12.9	MW	0.6
All pig slurry	33.2	MW	1.4
Cow solid manure addition	9.8	MW	0.4
Pig solid manure addition	14.8	MW	0.6
Total techno-economic potential (slurry + solid manure)	**70.7**	**MW**	**3.0**
Total techno-economic potential (slurry + solid manure)	**565.3**	**GWh[3]**	**3.0**

[1] Using most typical Polish manure characteristics, C:N 10-20, DM content in the reactor: 10% (National reference scenario for manure handling worked out in Work Package 5 of Baltic Manure Project, unpublished)

[2] Reference amounts (manure and energy potentials) are for farms > 100 LU (viable for biogas production),

[3] Assuming 8000 working hours for the biogas plant per year,

As mentioned earlier, the real challenge is to get the energy out of the vast amounts of solid manure. The geographical distribution of total techno-economic manure with division for solid manure and slurry is shown on Fig. 6.12. One can see that contribution of slurry to total manure is very low, varying between 3.3% for south-eastern parts to 7.7% in one southern voivodeships, having average of 5.7% for the whole country. Generally, central, eastern and south-eastern parts represent twice smaller contribution of slurry (3.3-5.3%) than western and northern regions (5.5-6.9%).

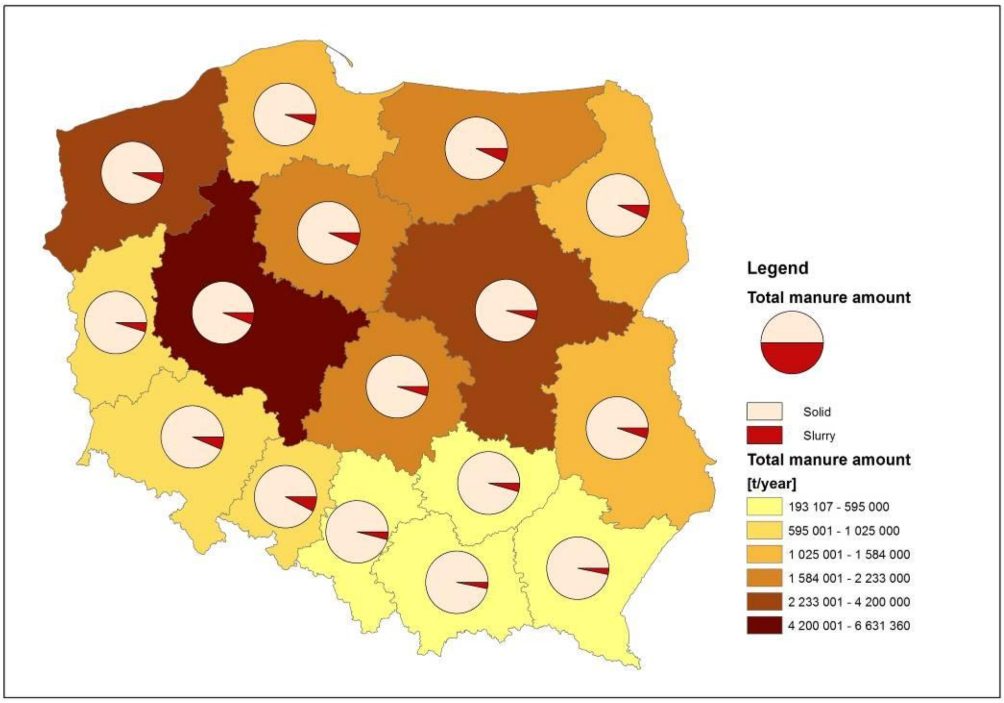


Figure 6.12. Geographical distribution of total manure on farms > 100 LU with division between solid and liquid manure for each voivodeshop. Source: POMCERT based on Eurostat.

7 Lithuania

Sigitas Lazauskas, Vita Tilvikiene & Virmantas Povilaitis

7.1 Background

Animal production is traditionally a very important sector of Lithuanian agriculture which experienced significant changes due to transition from planned to market economy and later due to joining EU. Among major trends of this two decade period, declining number of animals, specialisation and concentration of production can be mentioned. Currently (2013), the utilisation of the productivity of agricultural land in animal production is below potential - for example the number of cattle could be increased by 400 000, or by 62% with the application of more intensive and rational use of land resources (Mažvila et al. 2011).

Manure was traditionally considered as valuable fertilizer and soil improver, however, attitudes changed and today this valuable resource is often treated as an inevitable waste. Thus, biogas production from manure, a cheap raw material, seems attractive pathway of manure disposal.
In Lithuania, two biogas production units, one in Kaunas and another in Šakiai district, were constructed for large pig production factories, but currently there is no biogas production from manure in operation. Notwithstanding, projects of developing such biogas production units, especially on large pig factories, are in progress (2013).

According to previous estimations of the authors, the total amount of manure in Lithuania is more than 12 million tons per year (Luostarinen 2013). Solid cattle manure dominates, and together with slurry it comprises around 74% of all Lithuanian manure. The share of pig manure makes up 26%. However, only one third of the total manure amount is produced on large farms and can directly be considered as a feasible raw material for biogas production. Availability of co-substrates is also an important factor to consider when planning biogas plant capacities and location. At the farm level, maize usually is considered as a first choice of co-substrate. However, under Lithuanian conditions grasses should be given priority, at least due to environmental and sustainability reasons. Currently (2013), the area under maize production in Lithuania is steadily expanding, while the potential of grasses is not properly utilised. Agricultural, food industry and municipal waste provides another large potential source of co-substrates, however, developers of biogas should be aware of various specific risks related to e.g. hygiene.

7.2 Methodology

The total amount and regional distribution of manure and technical potential of biogas production from manure in Lithuania was estimated based on the number of cattle, pigs and poultry as provided by Statistics Lithuania. The area under maize and grasses was taken from the report of Agricultural Information and Rural Business Centre "Informacija apie 2012 metais Lietuvoje deklaruotas žemės ūkio naudmenas, miškus ir kitus plotus" (Information on declared agricultural land, forests and other areas in Lithuania in 2012).

Data on animal numbers and farm distribution according size and type of animal housing was taken from the Agricultural Census representing data from the year 2010. Manure amounts were estimated using coefficients recommended by *Orders of Minister of Agriculture* for designing cattle and pig farm buildings. Recalculation of number of animals to LU was made based on coefficients recommended by *Order of Minister of Environment and Minister of Agriculture.*

Manure amounts were counted correspondingly to previous Baltic Manure Report (Luostarinen 2013). The techno-economical potential of biogas production was based on manure production potential in "large" farms with more than 100 LU. Splitting farms in 2 groups (below 100 LU and above 100 LU) was based on figures provided in „Census 2010".

For this scenario, pig farms with more than 1000 animals were included into the "large" farms. Cattle farm group with animal number of 100 - 200 was split, and 25 percent was moved to "small" farms and 75 percent to "large" farms. Discrepancies between the different grouping of animals in Census and other documents were partly solved by calculating averages for different types of animal and housing. Average pasture period was assumed to be 5 month (taking into account that according to Census 2010, almost 85% of animals are kept outside for 5-6 month).

7.3 Manure biogas scenario for Lithuania

7.3.1 Mapping the location of manure / energy potential

Due to different natural and geographical conditions, the history of social and economic development in Lithuania can be divided into three major parts: Western, Central and Eastern. The most fertile soils with relatively high agricultural potential and intensive cash crop (grain, rape, sugar beet, maize) production are located in the Central part of the country. The soils in the Western part are generally hilly and of lower fertility, however, pastures and grassland provide a good basis for cattle rearing. The soils in the Eastern part of the country are hilly and unfertile, thus yield potential of field crops and pastures is low. However, development of animal husbandry and amounts of manure produced only partly reflects the diversity of these conditions.

Areas with high manure production can be found in all parts of Lithuania; however, it is more typical of Western and partly Central Lithuania (Figure 7.1). The manure energy potential is closely related to the amounts of manure produced, thus in general higher manure energy potential is also in the Central and Western parts of Lithuania (Figure 7.2). However, large pig and poultry production farms operate also in the Eastern part of the country.

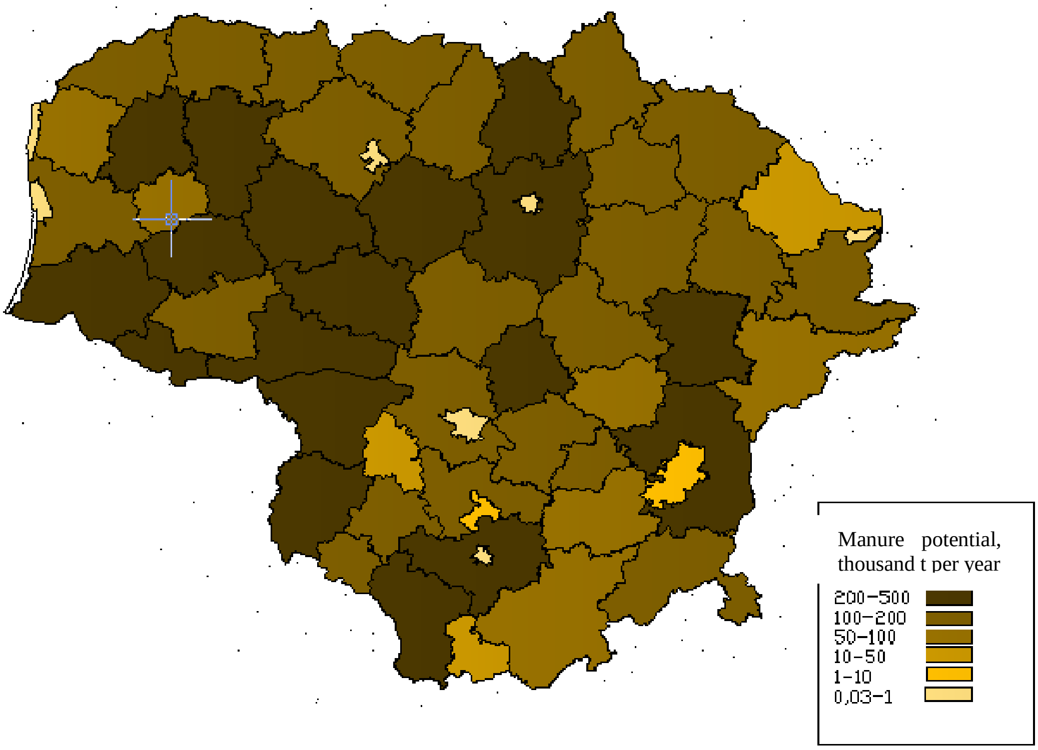


Figure 7.1. Manure potential (cattle, pigs and poultry), x 1000 t per year per district.

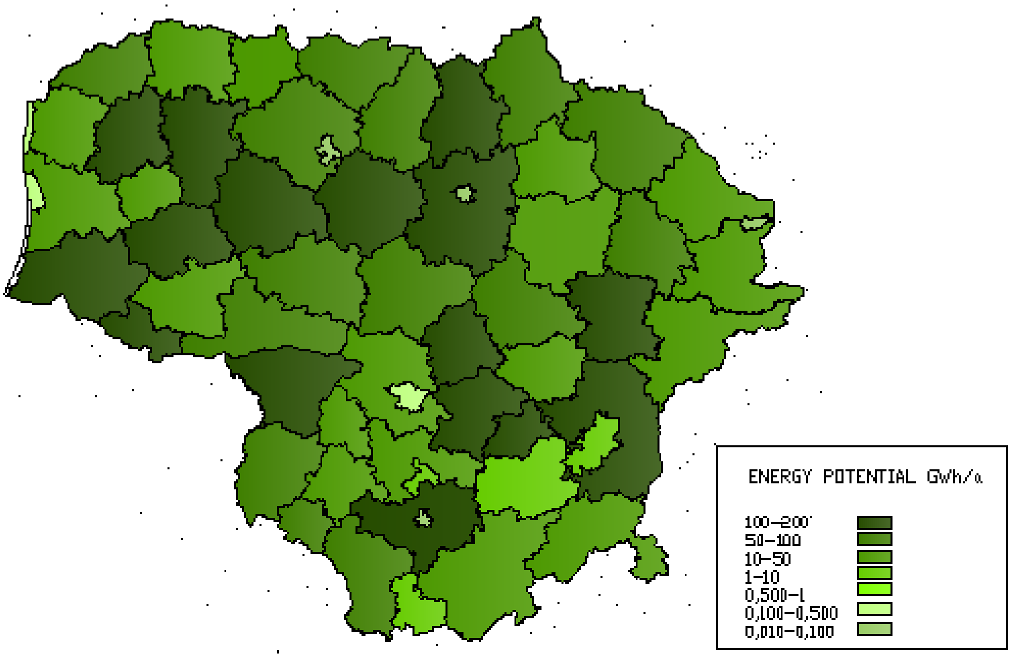


Figure 7.2. Biogas energy potential, produced using all types of manure from small and large farms, GWh/a

7.3.2 Estimation of possible amount and scale of biogas plants required

At the moment (2013), there are no manure-based biogas plants in operation in Lithuania. However, the recently announced plans to build nine biogas plants in the farms of the major pig producer "Saerimner" in Lithuania (Figure 7.3) can change this situation in the nearest future.

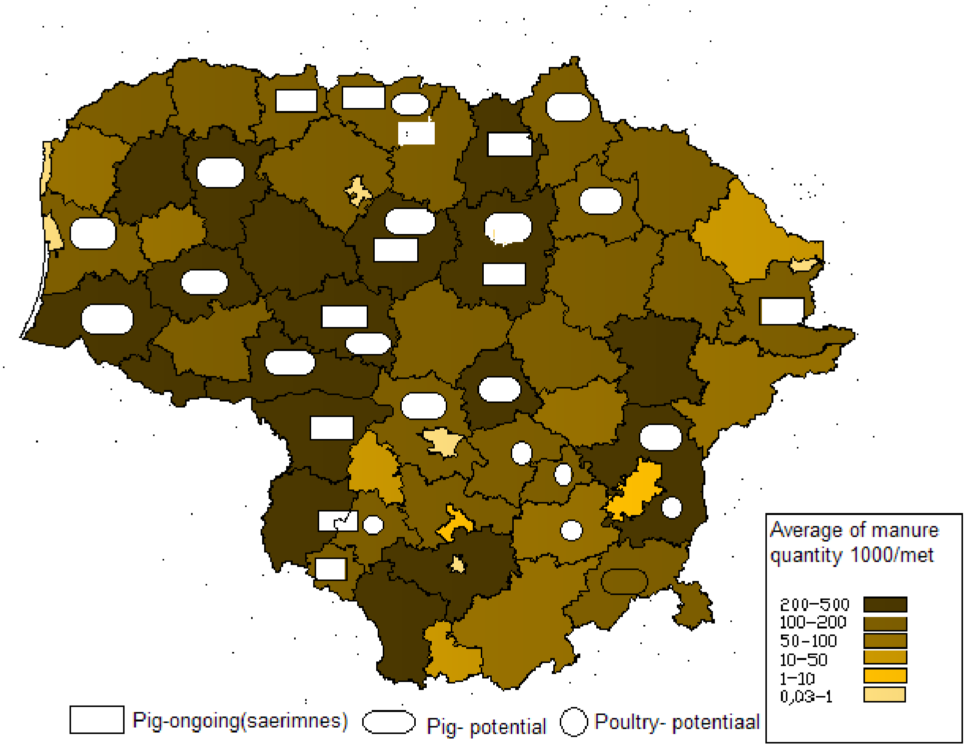


Figure 7.3. Location of the largest pig and poultry farms, including those belonging to "Saerimner" on the Lithuanian manure map (http://www.saerimner.lt/doc/45-sae-wwwpdf).

The largest farm complexes produce about 25% of all manure in Lithuania. Siauliai and Panevezys regions have the highest potential energy value for pig and cattle breeding complexes, and the Kaunas region for cattle and poultry complexes. A study performed by the Lithuanian Energy Institute (Jurkšienė and Lisauskas 2010) showed that biogas can be competitive to natural gas and attractive for investors, if it is produced from 20 to 50 t/day of manure. If such an assumption is applied, the number of potential farm-scale biogas plants in Lithuania is around 330.

7.3.3 Estimation of possible co-substrates available for manure-based biogas plants

A wide range of co-substrates can be considered in relation to biogas production from manure (Figure 7.4). Among the most promising, well-known and efficient co-substrate for biogas production is maize. Maize production (area) in Lithuania is steadily expanding – mostly in the Central part of the country (Figure 7.5). However, wide scale maize production for biogas production can be environmentally unsustainable. Thus, also the potential of using grass in biogas production should be considered. The Lithuanian grass pastures and natural grasslands are spread across the country (Figures 7.6., 7.7., 7.8) and potentially offer a steady flow of co-substrate for manure-based biogas production.

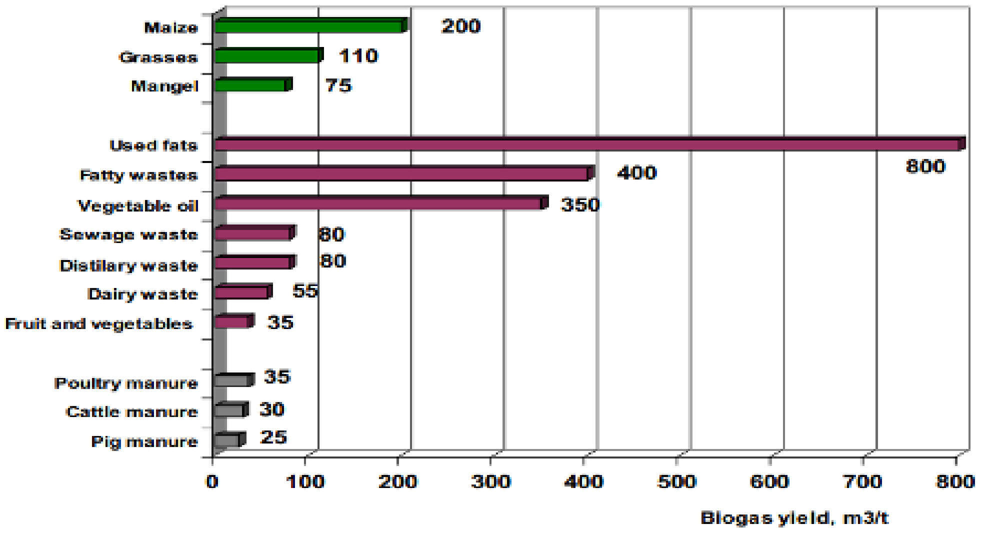


Figure 7.4. Biogas yield of different substrates (from Navickas K. & Pesta G. 2005)

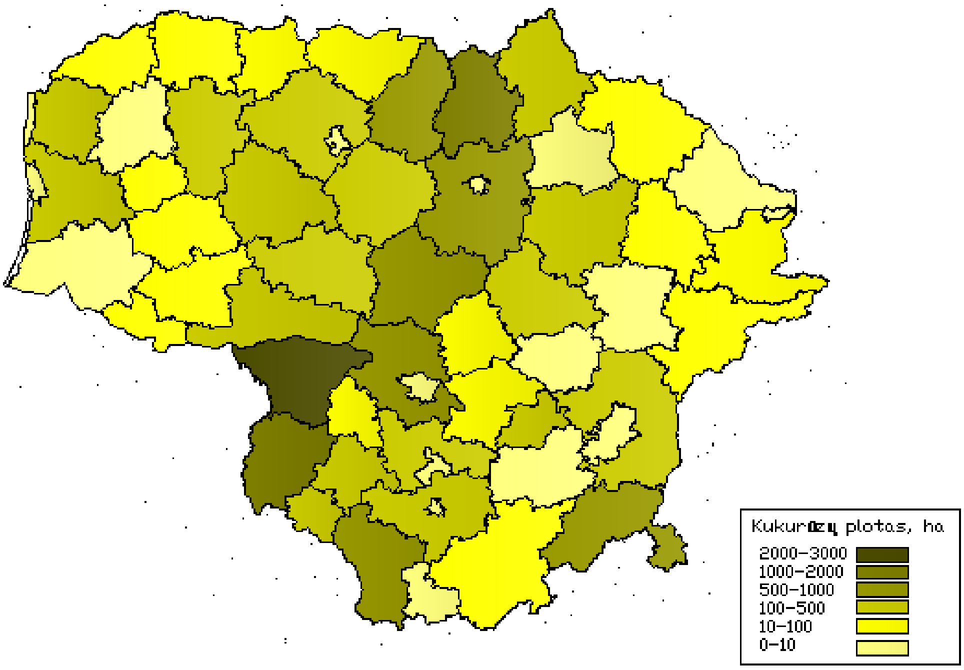


Figure 7.5. Maize area distribution in Lithuania, ha.

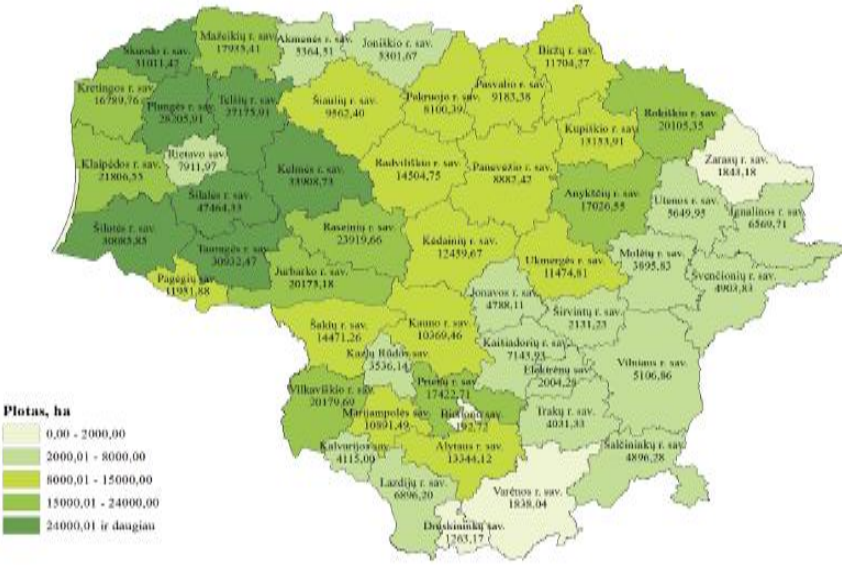


Figure 7.6. Area of pasture (up to 5 years).

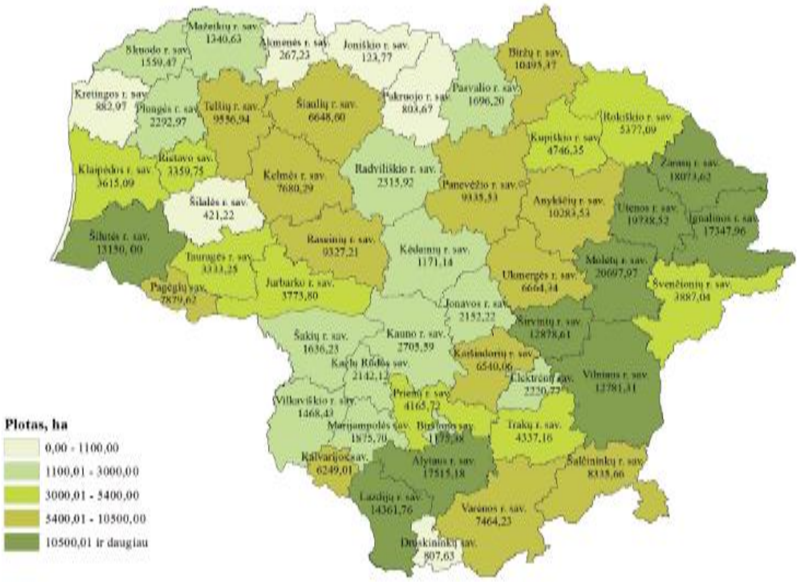


Figure 7.7. Area of pasture (more than 5 years).

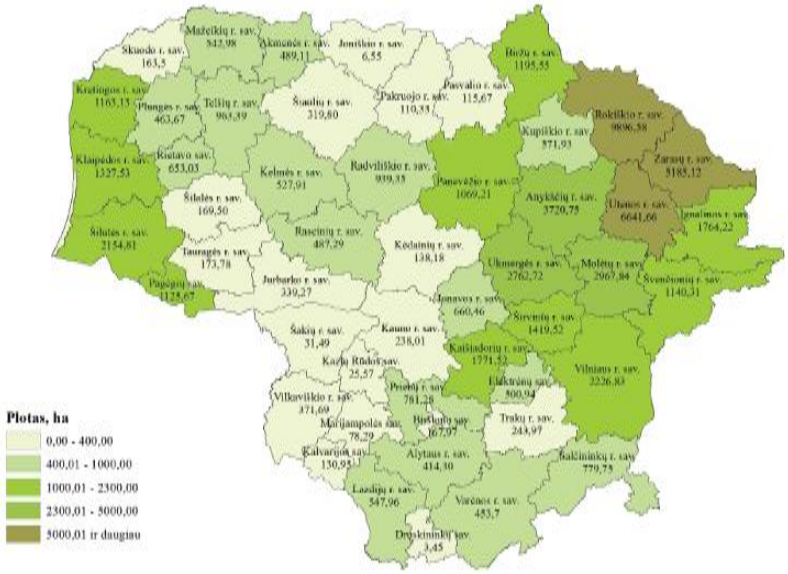


Figure 7.8. Area of natural grasslands.

7.3.4 Investment costs for the implementation of the energy potential

There are no working biogas plants for manure at the moment in Lithuania. However, it has been estimated that the investment for 1 kW of efficiency costs about 10 – 20 thousand Lt (2800 – 5800 EUR). Estimations performed by the Lithuanian Energy Institute (Jurkšienė and Lisauskas 2010) suggests, that only large farms, with more than 500 cattle or over 5000 pigs has real potential and market opportunities for biogas development under the current economic conditions.

7.4 Vision for 2025

The Baltic Manure vision is to convert 25% of total manure produced in Lithuania to biogas by 2025 seems very ambitious taking into account the very limited development so far. With the low price of electricity, the main driver for biogas production from manure seems to be necessity to cope with environmental requirements, rather than economical benefits. Thus a comprehensive package of promotional measures, including financial incentives, should be prepared in order to stimulate biogas production from manure in Lithuania.

Taking into account that currently getting profit from biogas plant is difficult in Lithuania because of the low price of electricity, fast expansion of manure treatment to biogas can be expected mainly in large pig production farms which face heavy pressure from environmental inspections and society. As it was mentioned before, the major pig producer “Saerimner” in Lithuania is going to construct nine biogas plants in a nearest future (after 2013). If majority of large pig producers will follow such an example, approx. 30 biogas plants with capacity of 1 MW each can be constructed until 2025. As a result approx. 120 direct jobs in biogas plants will be created, almost 10% of total national annual manure amount will be treated and around 3000 ha of maize or equivalent areas of grass will be directly utilised for production of co-substrate.

Large poultry producers also can benefit from biogas production; however, currently there are no clear indications that they are going to use this pathway of manure disposal. Nevertheless, it is likely that 2-3 biogas plants with some 10 direct job places can be constructed in poultry husbandry.

Cattle farms have the largest share in national manure amounts, however, biogas production in these farms are not as unambiguous as in pig farms. Estimations, taking assumption that majority (80%) of the largest cattle farms will choose biogas production, result in 112 biogas plants with a capacity up to 1 MW, 336 jobs, and area of 6800 ha of maize, or equivalent area for production other co-substrate biomass. Such a scenario, jointly with the one proposed for pig farms, can secure the target to convert to biogas 25% of total manure produced in Lithuania in 2025. Although some large cattle farms are planning to construct biogas production units, currently framework for such fast development is not very favourable.

Although small and medium sized farms still produce large amounts of manure, the expected contribution to biogas production in the nearest future seems to be rather limited. In contrast to large producers, small and even medium sized farms have very limited financial and human capacities, and need financial and information support as well as economically successful examples nearby. An optimistic guess of biogas production on these farms results in some 30 biogas plants, with direct jobs for 45-60 persons. Cooperation of farmers in Lithuania is still rather weak, thus fast development of such type of biogas production it is not very likely. Nevertheless, a few biogas plants can be established, especially if local authorities will lead such an initiative.

8 Latvia

Valters Kazulis, Arvids Celms & Vilis Dubrovskis

8.1 Background

The total energy potential from manure in Latvia is 741 GWh per year - 468 GWh/a from cattle manure, 122 GWh/a from poultry manure and 151 GWh/a from pig manure (2011 data; Dubrovskis et al. 2011). Estimated investment costs for building a biogas plant of 1 MW_{el} are approximately 2.8 million LVL (3.97 million Euros).

In December 2012, 36 cogeneration plants were using biogas as fuel (Central Bureau of Statistics). Installed electrical capacities of currently operating biogas plants are from 0.25 MW to 2 MW. Total installed electrical capacity of those cogeneration plants is 42.4 MW of electricity and 46.6 MW of heat. In compliance with the directive 2009/28/EC, Latvia plans to increase total installed electrical capacity of biogas plants to 92 MW by 2020.

To utilise all manure from the previously estimated techno-economical energy potential (Luostarinen 2013), biogas plants with a total power of 33.8 MW_{el} ought to be built. Theoretically then there are already enough biogas plants built to utilise all manure from the techno-economical potential.

Cattle manure, maize and other silages are favoured substrates for biogas production. However, manure can be considered more as an additive in substrates. This can be explained by the following reasons:

- Legislation has not been enforcing / stimulating manure utilisation as a substrate
- Farms have significant land resources (to grow energy crops) but comparatively small numbers of livestock per farm (largest 1500 cows)
- Majority of biogas plants belong to a particular farm
- Manure-based biogas alone gives smaller methane yields than co-digestion with other substrates
- Farms are not cooperating with manure utilisation and manure transportation is expensive
- Existing biogas plant locations do not enhance biogas production from manure
- Building biogas plants smaller than 0.25 MW has not been economically attractive

Biogas plants use cogeneration (CHP) technologies for burning biogas and producing electricity and heat. Still, there are rarely opportunities to sell the heat as the majority of biogas plants are located further away from residential areas. Despite this, cogeneration technologies are employed because biogas is supported through obtaining the rights to sell the electricity produced through mandatory procurement for a set feed-in tariff and through payments for installed capacities.

Climate Change Finance Instrument (CCFI) is a state support promoting technological changes from fossil to renewable in Latvia. CCFI is oriented more towards housing renovation and is not a source of significant support for biogas sector. Initially, biogas plants could get 13 Euros for a ton of CO_2 equivalent saved through CCFI, now it is five Euros. The state has not been providing other technology and investment support mechanisms to compensate for this decrease.

International public instruments to support the initial investment and finance of biogas plants are available from the EU structural funds and programs of the European Economic Area and the Norwegian Financial Mechanism. However, on 28.08.2012 the Latvian government suspended the support for renewable energy and cogeneration power plants. There will not be tendering held for rights to sell biomass, biogas, solar and wind generated electricity under the mandatory procurement until 01.01.2016 (Ministry of Economics).

Biogas is not used in local transportation systems and purification of biogas to biomethane is not practiced. The connection of biogas plants to natural gas grid has been hindered by Gas of Latvia having exclusive rights of supply and distribution of gas until 2017. Partly owned by Russian Gazprom, Gas of Latvia is a significant player in the local energy market lobbying natural gas and baffling the advancement of local bio-energy sector. Ironically, the largest part of mandatory procurement is paid for natural gas. Mandatory procurement is 1.23 sant/kWh (1.75 EUR cents/kWh) – renewable energy component is only 0.29 sant/kWh (0.41 EUR cents/kWh), remaining part 0.94 sant/kWh (1.34 EUR cents/kWh) is surcharge for natural gas cogeneration.

Governmental support mechanisms have been accused of being tailored for certain people / interest groups instead of truly promoting sustainable renewable energy. The yet to be passed new energy law has been much debated. It promises support for biomethane; however, the support mechanism is unclear.

Other amendments to the support mechanisms state that purchase contract with RES and cogeneration plants are planned to be signed for ten years and prioritise plants using manure. Annual statistics show farm sizes are growing. Yet local peculiarities make it unreasonable to require great amounts of manure as a substrate for every biogas plant. Still, it will be beneficial to create ‘carrot’ incentives for biogas plants to increase manure use. The new law promises to require at least 30% of substrate to be manure.

8.2 Current (2013) biogas production in Latvia

A national scenario for harnessing the manure energy potential as biogas is unclear as much depends on the state’s strategy and the new energy law which still has not been finalised. During the time of preparing this report (late 2013) the parliament approved renewable energy resources temporary tax package as a part of the 2014 budget. The tax will be collected during the three following years, 2014 - 2016. The package introduces three tax groups: 15% tax will be applied to natural gas stations; 10% tax will be applied to renewable resource plants and 5% tax will be applied to the plants that provide centralised systems with heating and where the application of higher tax would directly affect the consumers. 5% will also be applied to producers, who use (by)products of animal origin or derivative products and where the produced heat is used for (further) production. Some agents view the package as a double turnover tax and claim action will be taken against implementation of this tax. A way of explaining the current situation might be acknowledging the initial support mechanism had not been designed green enough and had such

‘’holes’’ that let some abuse this mechanism to produce not-very-green energy (under disguise of greener energy) for greater price than the other (non-green) energy. The governments have been changing and maybe each government has tried to tailor certain things according to some ‘’guidance’’. Whatever the intentions of the current government are, it is somewhat tied to the liabilities that have been set by its predecessors.

The study "Latvian Energy Policy: Towards Sustainable and Transparent Energy Sector " (Spruds et al. 2009) emphasised the lack of transparency in politics giving strong evidences that state’s strategic planning came secondary to business interests of certain lobbies. Wherever EU directives leave enough room for maneuvering the ruling governments have made policies that are questionable from sustainable strategic planning perspective. Due to such actions, the purification of biogas to biomethane has yet to be introduced in local biogas sector.

Biogas production is not yet profitable /attractive without any support mechanisms / incentives in Latvia. The support mechanisms available so far have not been oriented towards encouraging manure utilisation in biogas production. Regardless, in compliance with the directive 2009/28/EC Latvia plans to have total installed electrical capacity of biogas plants of 92 MW in year 2020. This is nearly double of current situation as in 2012 it was 42.4 MW. In the end, the number of biogas plants in Latvia could grow up to 50. Among Latvia’s renewable energy goals is achieving 10% biofuel consumption from the total fuel consumption in transport by 2020 - in 2011 it was 4%.

Table 8.1 shows the locations and capacities of biogas plants in Latvia in December 2012. Saldus, Iecava, Ķekava, Madona, Ventspils, Talsi, Tukums, Dobele, Jelgava un Smiltene and Gulbene municipalities (Figure 8.1) can be considered the hotspots of manure energy. There were no biogas plants Ķekava, Ventspils, Talsi and Smiltene municipalities. The locations of biogas plants in Latvia do not match the manure hotspot areas. Thus, manure energy potential in Latvia is yet to be utilised.

Figure 8.1. Municipalities in Latvia.

Table 8.1 Biogas plant locations in December 2012 (Spruds et al. 2009).

Name of company	Electrical capacity (MW)	Location
SIA "BIO FUTURE"	1	"Smaidas", Vaiņodes pagasts, Vaiņodes novads
SIA "GAS STREAM"	1	"Smaidas", Vaiņodes pagasts, Vaiņodes novads
SIA "RZS Energo"	0.526	"Lāses", Sesavas pagasts, Jelgavas novads
SIA "BIO Auri"	0.6	"Pogas 1", Kroņauce, Auru pagasts, Dobeles novads
SIA "Zemturi ZS"	0.7	"Zemturi", Burtnieku pagasts, Burtnieku novads
SIA "Kņavas granulas"	0.5	"Granulas", Viļānu pagasts, Viļānu novads
SIA "ZAAO Enerģija"	0.35	CSA poligons "Daibe", Stalbes pagasts, Pārgaujas novads
AS "Viļānu selekcijas un izmēģinājumu stacija"	0.95	"Piziči", Viļānu pagasts, Viļānu novads
SIA "Pampāļi"	1	"Auniņi", Pampāļu pagasts, Saldus novads
ZS "Līgo"	0.5	"Līgo", Lielplatones pagasts, Jelgavas novads
SIA "Conatus BIOenergy"	1.96	"Graudiņi", Sausnējas pagasts, Ērgļu novads
SIA "Bioenerģija-08"	1.96	"Jaunlīci", Poļvarka, Sarkaņu pagasts, Madonas novads
SIA "Zemgaļi JR"	0.5	"Nārzbūti", Vircavas pagasts, Jelgavas novads
ZS "Jaundzelves"	0.526	"Jaundzelves", Katvaru pagasts, Limbažu novads
SIA "Biodegviela"	1.9	Rūpnīcas iela 15, Kalsnavas pagasts, Madonas novads
SIA "Agro Lestene"	0.5	"Saulīšu ferma", Lestenes pagasts, Tukuma novads
SIA "Agro Iecava"	1.95	"Latvall-Jaunlūči", Iecavas novads
SIA "BP Energy"	0.25	"Krastmalas", Allažu pagasts, Siguldas novads
SIA "MC bio"	0.996	"Mežacīruļi", Zaļenieku pagasts, Jelgavas novads
SIA "Sidgunda BIO"	0.6	"Niedras", Sidgunda, Mālpils novads
SIA "RZS ENERGO"	0.998	"Lāses", Sesavas pagasts, Jelgavas novads
SIA "Bērzi Bio"	0.526	"Bērzi", Mālpils novads
SIA "Rigens"	1.998	Dzintara iela 60, Rīga
SIA "AD Biogāzes stacija"	1.96	"Skaista", Skrudalienas pagasts, Daugavpils novads
SIA "Daile Agro"	1	"Vecsmildziņas", Glūdas pagasts, Jelgavas novads
SIA "Zaļā Mārupe"	1	"Imaku ferma", Jaunmārupe, Mārupes novads
SIA "NOPA LTD"	0.25	"Asinovka", Šēderes pagasts, Ilūkstes novads
SIA "BIO ZIEDI"	1.998	"Kalna Oši", Dobeles pagasts, Dobeles novads
ZS "Jaundzelves"	0.526	"Jaundzelves", Katvaru pagasts, Limbažu novads
ZS "Līgo"	0.5	"Līgo", Lielplatones pagasts, Jelgavas novads
SIA "EcoZeta"	0.98	"Slovašēni", Cesvaines pagasts, Cesvaines novads
SIA "Zemgaļi JR"	0.6	"Bionārzbūti", Vircavas pagasts, Jelgavas novads
SIA "Agro 3"	0.5	"Cemeri", Litenes pagasts, Gulbenes novads
SIA "Piejūra Energy"	1.6	"Līvi", Nīcas pagasts, Nīcas novads

8.3 Methodology

Technology scenarios for implementation of manure energy potential as biogas have been prepared for the administrative divisions of Latvia. Latvia is divided in 110 municipalities and nine cities. The area of municipalities in Latvia varies. If a biogas plant is planned as a separate business or a farm alone cannot provide enough raw materials for substrate, the subsequent increase in the required transportation distances (including neighbouring municipalities) is not taken into account in this study.

The maps of animal locations in Latvia include farms with more than 100 cattle units, 1000 pig units and 5000 poultry units. Data on animal numbers has been accessed from Central Statistical Bureau and Agricultural Data Centre websites. Available manure amounts have been estimated using the livestock data together with average daily amounts of manure per livestock unit. Energy potential calculations were done taking into account average, organic matter and dry organic matter in different manures in Latvia, average amounts of biogas yields from anaerobic digestion, and averages of methane content that can be harnessed from different manures. Estimates for calculations are given in Table 8.2.

Table 8.2. Estimates for calculations on the Latvian manure biogas scenario (Dubrovskis 2012).

	Manure from one cattle per day (kg)	Dry matter (%)	Dry organic matter (%)	Biogas produced from one t_{DOM}	1m^3 biogas generate (kwh)
Cattle	45	14	88	300	5.8
Poultry	0.15	22	80	510	6.0
Pigs	4.5	15	86	500	6.0

8.4 Manure biogas scenario for Latvia

The cattle, pigs and poultry production are differently concentrated in different municipalities (Figures 8.2, 8.3, 8.4). This inevitably also effects the location of manure energy potentials and the most potential location for biogas plants digesting manure.

The greatest numbers of cattle livestock can be found in Saldus municipality (9400) and in Tukums municipality (6600; red in Figure 8.2). Smiltene, Madona, Talsi, Ventspils, Gulbene and Jelgava municipalities (blue in Figure 8.2) have 5000-6500 cattle in each municipality. Also, Kuldiga and Dobele municipalities (light green in Figure 8.2) have 3500 -5000 cattle.

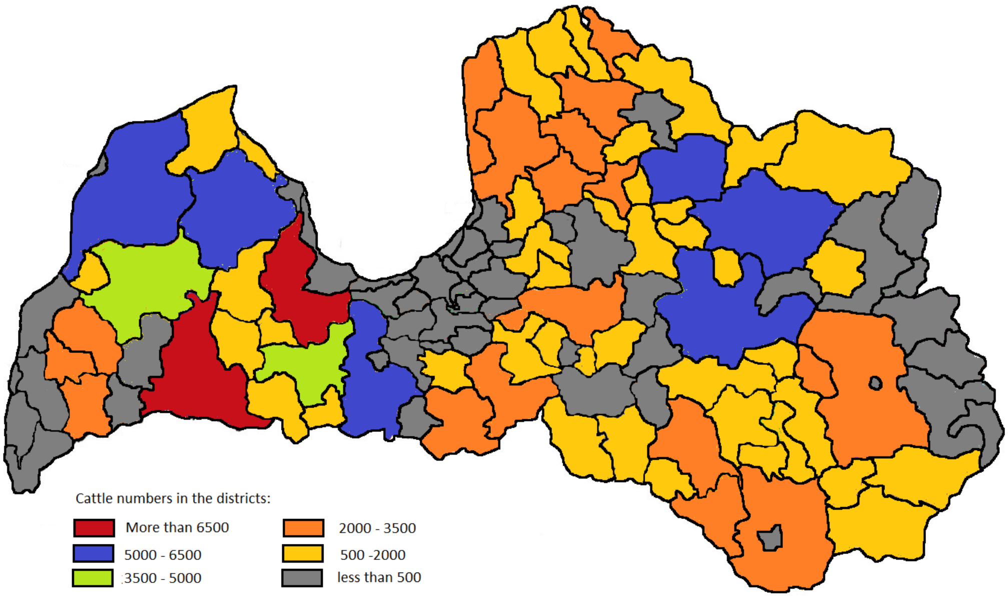


Figure 8.2. Cattle on farms with more than 100 animals in Latvia (Dubrovskis et al. 2011).

The greatest numbers of poultry livestock are in Iecava municipality (1 954 087) and Kekava municipality (1 667 000; red in Figure 8.3), and also in Madona municipality (150 650; light green in Figure 8.3). A large egg producer 'Balticovo' located in Iecava district alone keeps nearly 2 million poultry units.

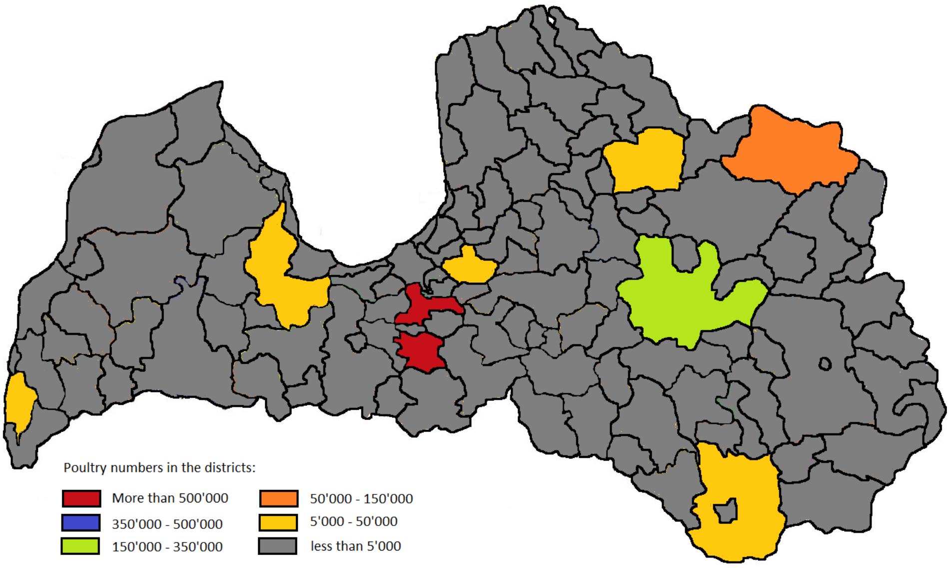


Figure 8.3. Poultry on farms with more than 5000 animals in Latvia (Dubrovskis et al. 2011).

The greatest numbers of pig livestock can be found in Salas municipality (33 921; red in Figure 8.4). Saldus municipality (blue in Figure 8.4) has 20 000 - 25 000 pigs and the neighbouring Auce, Dobele, Vainode and Aizpute municipalities have 15 000 – 20 000 pigs.

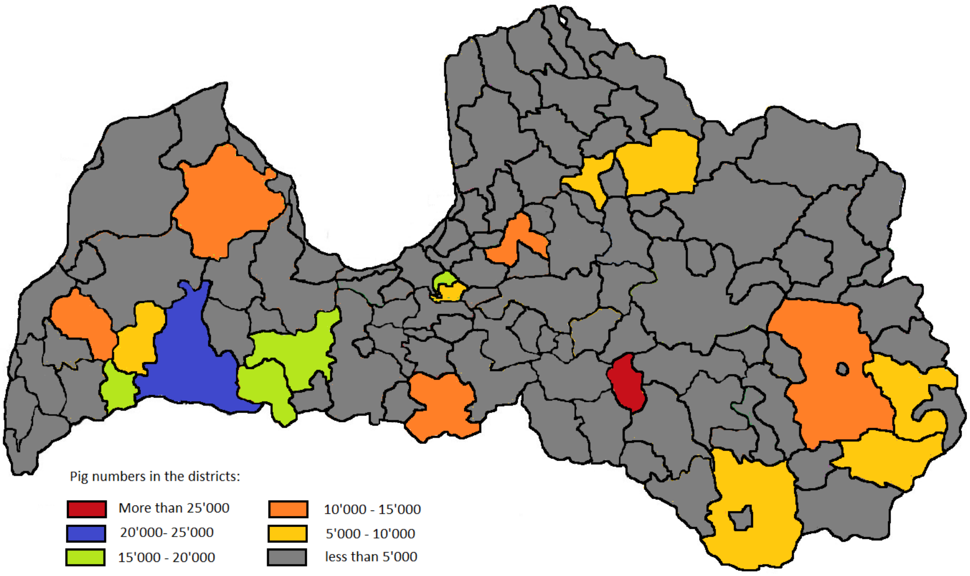


Figure 8.4. Pigs on farms with more than 1000 animals in Latvia (Dubrovskis et al. 2011).

8.4.1 Total manure amount

The amount of dry organic matter (volatile solids, VS) in different manures in the municipalities of Latvia anticipates the energy potential of the manures as biogas. The highest amounts of dry organic matter in manure are available in Saldus and Iecava municipalities (red, Figure 8.5), being more than 20 000 tons per year. Moreover, 15 000 – 20 000 tons of dry organic matter in manure per year can be obtained in Ķekava and Madona municipalities (blue, Figure 8.5). Ventspils, Talsi, Tukums, Dobele, Jelgava, Smiltene and Gulbene municipalities (light green, Figure 8.5) have 10 000 – 15 000 tons of dry organic matter in manure per year. In Saldus district, most of the available manure is cattle manure (9400 livestock units in the district). In Iecava and Kekava districts are the two of the biggest poultry farms in Latvia with 2 million and 1.5 million poultry units.

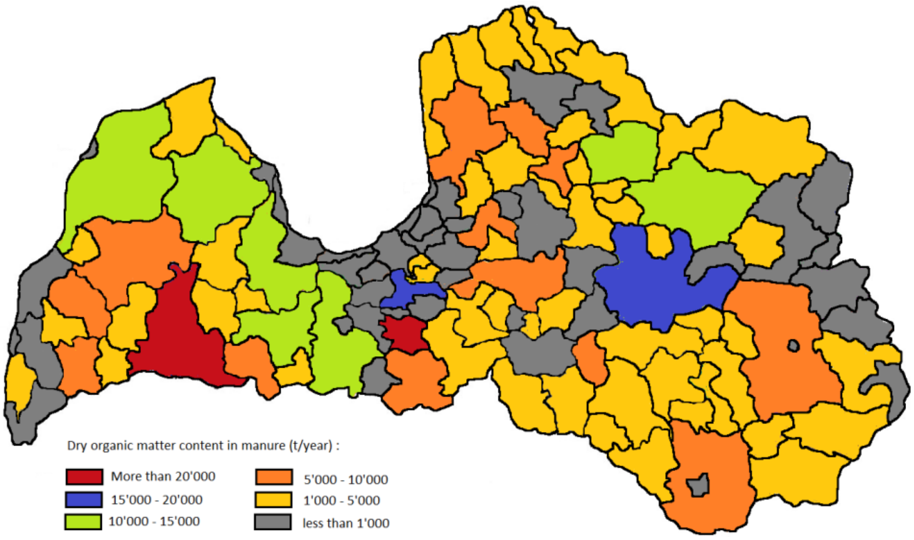


Figure 8.5. Dry organic matter content in Latvian manure (Dubrovskis et al. 2011).

8.4.2 Total Energy Amount

The amounts of manure available on the large farms can be directly converted into manure energy potential as biogas. The greatest energy potential lies in Iecava and Kekava municipalites (red, Figure 8.6), Saldus (blue, Figure 8.6) and Talsi, Dobele and Madona municipalities (light green, Figure 8.6). With this information, it is possible to roughly estimate how these municipalities could implement the biogas production from manure.

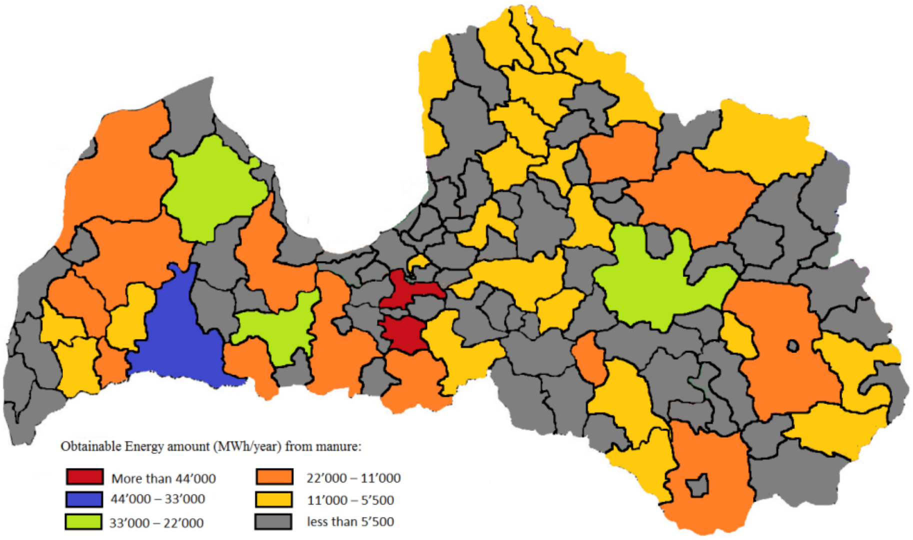


Figure 8.6.Obtainable energy amount from manure in Latvia (Dubrovskis et al. 2011).

8.4.3 Possible Scales of Biogas Plants

With the information on the highest manure energy potential, it is possible to estimate the scales (power MW_{el}) of biogas plants digesting only manure in the municipalities of Latvia (without considering transportation). Of all the red municipalities (Figure 8.7), in Iecava (red, Figure 8.7) municipality, the manure energy potential allows building one 2.65 MW_{el} biogas plant, while in Kekava municipality, the manure energy potential allows building one 2.2 MW_{el} biogas plant. Saldus municipality could build a 1.92 MW_{el} biogas plant, and Talsi, Dobele and Madona municipalities biogas plants each have an output of more than 1 MW_{el}. Moreover, Ventspils, Tukums, Dobele, Sala, Smiltene, Gulbene, Rezekne and Daugavpils municipalites (blue, Figure 8.7) could each have a manure-based biogas plant with an efficiency of 0.75-1 MW_{el}.

None of the currently (2013) operating biogas plants, however, is digesting only manure in Latvia. The legislation in effect do not define any requirements for manure amount in the substrates, allowing operators of the biogas plants to co-digest manure with other substrates with a focus on producing greater methane yields, focusing less on the environmental aspects.

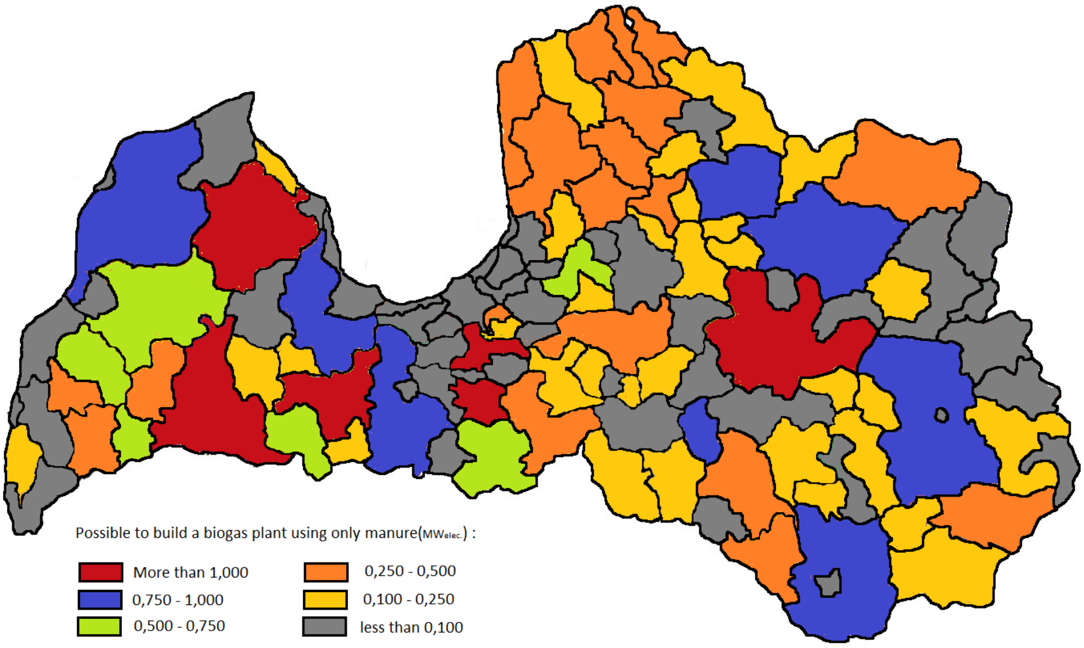


Figure 8.7. Possible scales of only manure digesting biogas plants (Dubrovskis et al. 2011).

8.4.4 Estimation of possible co-substrates available for manure-based biogas plants

There are unmanaged arable lands in the municipalities of Latvia that potentially could be available for growing energy crops. Land survey data (2010) showed 368 500 ha of unmanaged or minimally managed arable land defined as a land which has not been managed for two years. At least 1 000 ha of unmanaged arable land can be found in most of the Latvian municipalities.

The largest share of unmanaged lands is located in the East of Latvia – Latgale region is location to 27% of all unmanaged arable lands in Latvia (Dubrovskis et al. 2011; Figure 8.8). There is also more than 20 000 ha of unmanaged arable land in Rezekne municipality (red, Figure 8.8) and between 15 000 – 20 000 ha in Daugavpils municipality (blue, Figure 8.8). Additionally, 10 000 – 15 000 ha of unmanaged arable lands are in Ventspils, Madonas, Alūksne, Balvi and Ludza municipalities. When comparing the locations of manure (Figure 8.5), it can be seen that Ventspils, Madona, Rēzekne and Daugavpils municipalities are already favourable locations for biogas plants using manure. Co-digestion with energy crops could significantly increase biogas yields.

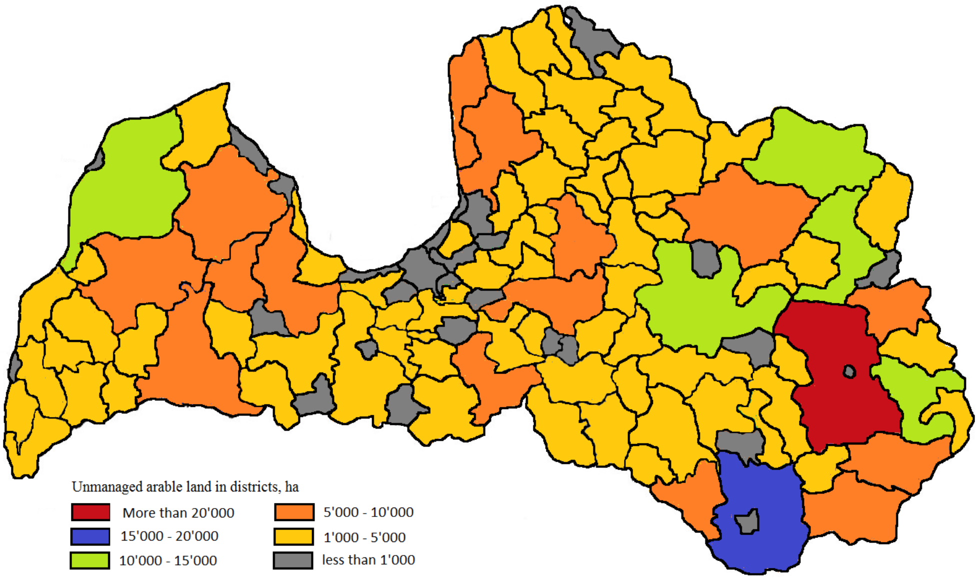


Figure 8.8. Unmanaged arable land in districts of Latvia (Dubrovskis 2012).

The possible obtainable energy amount from energy crops such as maize can be estimated if it was grown in the currently unmanaged arable lands. Rezekne, Ludza and Daugavpils municipalities (red, Figure 8.9) in Latgale region have the greatest potential – more than 400 000 MWh per year. Total energy potential from maize in Latvia would become 13 000 GWh/year. This is 16 times greater than the total potential of manure energy in Latvia (741 GWh/year).

Currently (2013), Latvian biogas plant operators favour energy crops. Manure is not the main ingredient as energy crops can be grown cheaply and are easy to transport and store. Often there is not much manure available nearby. Moreover, people do not favour cooperation and the transportation costs for manure are high.

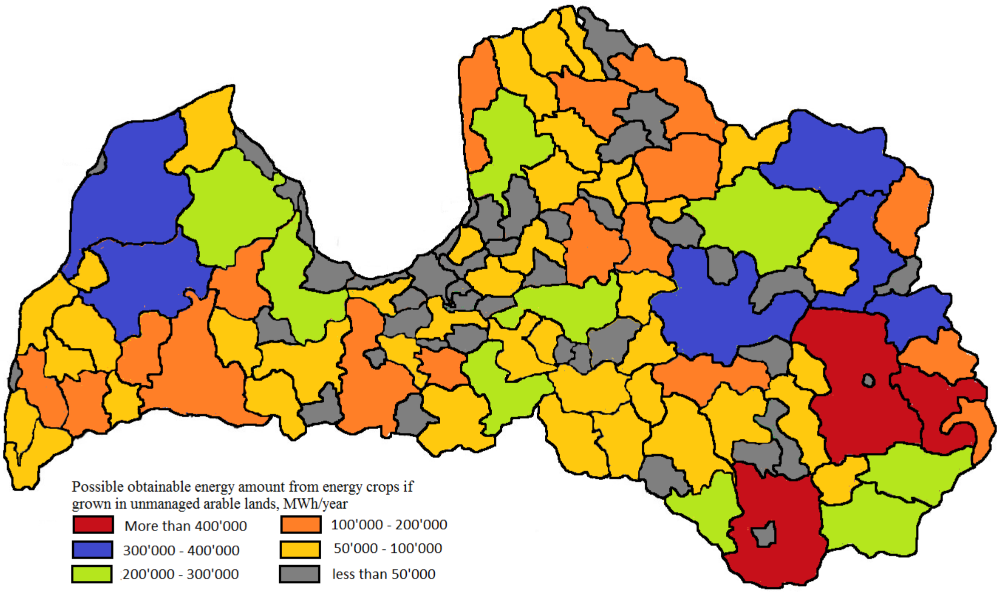


Figure 8.9. Possible obtainable energy amount from energy crops if grown in unmanaged arable lands (Dubrovskis 2012).

Obtainable energy amount from food processing by-products has been estimated for by-products from fruit and vegetable processing, dairy production and alcohol (mainly beer) production. The largest amount of food processing by-products are available in Riga city - approximately 35 000 MWh and Saldus municipality - approximately 12 000 MWh (red, Figure 8.10). A share of 54% from the total obtainable energy amount from food processing by-products is available in Riga. Most of the food processing by-products in Latvia are dairy production by-products. For dairy companies, whey is the greatest source of pollution. Using whey in biogas production would help to solve the problem of by-product processing in dairy production industry.

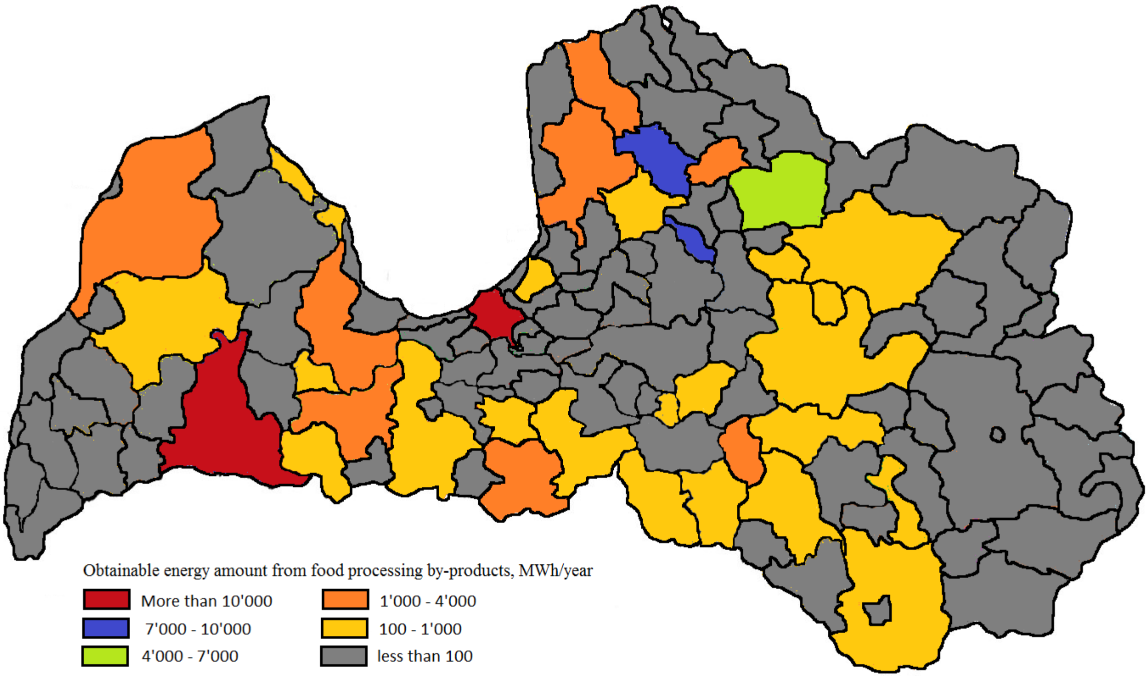


Figure 8.10. Obtainable energy amount from food processing by-products (Dubrovskis 2012).

8.5 Vision for 2025

Up to the time of writing (2013), biogas producers in Latvia do not have to follow any regulations how much manure should be digested in biogas plants. . Still it might be problematic to make long-term business plans due to frequent changes in laws and regulations. A lack of (accountable) sustainable vision is highlighted by the current situation where there is no agent / agency collecting and analysing the information on manure use in biogas production in Latvia. Ministry of Economics representative stated that they receive some data from biogas producers in Latvia, but no further analysis is carried out.

Ensuring more ecological development of biogas sector in Latvia requires clearer definitions and regulations (guidelines) as in many cases biogas production is more just a business as opposed to a ''greener'' business opportunity. Clearer governing / planning authority in this sector could be required - assuming the concept of successful green business does not exactly correspond with the idea of free market competition.

People who have, say, one or few livestock units should be encouraged to continue their practices also due to the often hostile environment for animals in the so-called 'factory farms'. Also vegetarian diets ought to be promoted.

In the areas where much manure is available, however there is no single bigger farm. Thus, farmers should be strongly encouraged to cooperate also within manure management.

9 Estonia

Tauno Trink, Ahto Oja & Argo Normak

9.1 Background

According to the National Renewable Energy Action Plan until 2020, Estonia has to ensure that the share of renewable energy has to increase to 25% of the gross final consumption of energy, namely 3 451 (thousand ktoe). Achieving these goals requires work in both local and regional level and biogas plays an important role. Biogas production and usage is a relatively new issue in Estonia, but it shows signs of progress and increased activity. Despite few biogas producing units in Estonia at the moment (2013), it should be noted that biogas field is very young and still under development phase, concerning practical experience, know-how, political contribution and subsidies. Considering the current economic situation in Estonia and the (un)profitability of bioenergy, it is clear that the transfer to bioenergy will not take place without political decisions and subsequent financial support schemes.

In the case of biogas, support mechanisms should take into account the source of biogas as well as location and size of the plant. In current price premium system for all kinds of renewable electricity (0.053 €/kWh), it is not feasible to produce biogas for electricity generation. Also the production cost of biomethane (98±1 % CH_4) is higher than the price of natural gas in Estonian filling stations. The price of CNG for a final consumer in the filling stations of AS Eesti Gaas was 0.779 €/kg, (VAT 20%) in June 2013 (without VAT and in cubic meter equivalent 0.46 €/m^3).

The first priority for biogas production is to use all possible organic waste, leftovers and manure, as those substrates already exist and in this case the production cost is lower. If the biomethane is used in local agricultural transport off-grid from natural gas grid then it might be economically feasible. To find out the costs and benefits of biogas production from manure, leftovers and other organic waste, the Estonian biogas potential is identified, most promising locations are put on GIS-based map and based on this, two scenarios are formulated, including technology, biogas capacity, number of biogas plants needed to use the energy potentials, use of residues, investment costs, potential social and environmental impacts, possible advantages and disadvantages for the environment, economical and new job and business opportunities with possible advantages and disadvantages for the manure-biogas business.

The objective of the manure energy scenarios is to find solutions for the use of manure in energy production in Estonia. Simultaneously, the prerequisites and actions required in order to implement the scenario in Estonia will be considered.

9.2 Methodology

Data of manure and co-substrates in the Estonian regions is based on the information from the Estonian Biogas Association (EBA), Agricultural Registers and Information Board (ARIB) and Environment Information Centre (EIC). Based on this data, a GIS-application (map) is created to show the manure volumes in different regions and the volumes of potential co-substrates and the most potential locations for biogas production. The results of other work packages and working groups of Baltic Manure project were used for creation of this strategy document. In addition to this, literature sources and previous biogas usage strategies and reviews were used as listed in the references.

9.3 Manure biogas scenario for Estonia

9.3.1 *Manure usage scenarios in energy management*

The total (including manure techno-economical potential), yearly feasible biogas resource is estimated to be 480 million Nm³/a in Estonia. This could supply approximately 732 000 people with electricity (1.41[1] MWh/person) and 245 000 people with heat (3.23 MWh/person). It could be used to produce annually 1032 GWh_{el} of renewable electricity, with electrical nominal power of 118 MW_{el}. The avoidable amount of CO_2 could range between 960 000 t/a (1 m^3 biogas for energy purposes reducing 2.6 kg CO_2-emissions[2]) and 1 083 000 t/a (1.05 t CO_2/MWh[3]). The annual biomethane (upgraded to 98±1 % CH_4) production from the available biogas could be 288 million Nm³, which is about 45% of Estonian annual natural gas consumption in 2011. Depending on the electrical capacity of a gas motor (0.5-1.0 MW_{el}), there could be 100-200 biogas plants in Estonia. It would be possible to produce approximately 10.26 % of the heat energy and 15.6 % of electricity used in Estonia from the applicable biogas quantity.

9.3.2 *The volume of investment*

In 2009, the Estonia Environmental Investment Centre supported the construction of four biogas plants (Aravete, Oisu, Vinni and Ilmatsalu) from the European Regional Development Fund (ERDF) measure called Production of energy from renewable sources. The total investment support for these agricultural plants was 5 million €. Thereby, there are at the moment three manure-based biogas plants in Estonia. In addition to these, one manure-based biogas plant has received investment support by the Estonia Environmental Investment Centre in 2009 but it is still under construction (2013). Lately it has been approved by the ministries that from 2015 onwards Estonia will contribute financially to biomethane production with 43 million €. By 2020, the use of biogas in the transport sector must replace 30.000 tons of oil use (30 ktoe). At the moment, all biogas

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[1] Web: Eesti elektrisüsteemi varustuskindluse aruanne 2012, http://elering.ee/public/Infokeskus/Aruanded/Elering_Varustuskindluse_aruanne_2012.pdf

[2] Environmental Aspects of Biogas Technology. Barbara Klingler. German Biogas Association, http://homepage2.nifty.com/biogas/cnt/refdoc/whrefdoc/d7env.pdf

[3] Biogaasi ressurss ja tootmine Eestis. Projekti W-Fuel andmebaasi loomine. Ü. Kask. Tallinna Tehnikaülikool, W-Fuel projekt. 2010. http://www.seit.ee/failid/638.pdf

plants in Estonia are producing electricity and heat, none of them are built for biomethane production.

1) Jööri Biogas plant (Saaremaa)

- started biogas production: in 2006
- total investment: 3.83 million €
- *not working properly

2) Aravete Biogas plant (Figure 9.1)

- started biogas production: in 2012
- total investment: 5.7 million € (25% was covered by investment support measure)
- capacity: 2 MW_{el}
- substrates: ~100 000 t/a biodegradable material (80% manure, 20% biowaste)[4]

3) Oisu Biogas plant (Figure 9.2)

- started biogas production: in 2013
- total investment: 4.9 million € (18% was covered by investment support measure)
- capacity: 1.2 MW_{el}
- substrates: ~74 590 t/a biodegradable material (100% manure; including liquid manure) [5]

4) Vinni Biogas plant (Figure 9.3)

- started biogas production: in 2013
- total investment: 5.1 million € (22% was covered by investment support measure)
- capacity: 1.36 MW_{el}
- substrates: ~88 000 t/a biodegradable material (95% manure, 5% silage)[6]

5) Ilmatsalu Biogas plant

- under construction (estimated to be operational in 2014)
- total investment: 5 million € (32% was covered by investment support measure)
- capacity: 1.56 MW_{el}
- substrates: ~90 000 t/a biodegradable material (85% manure and slurry, 15% biodegradable material)[7]

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[4] Info from Aravete biogas plant operator (12.06.2013)
[5] Info from Oisu biogas plant operator (12.06.2013)
[6] Info from Vinni biogas plant operator (12.06.2013)
[7] Info from Ilmatsalu biogas plant operator (14.06.2013)

Figure 9.1. Aravete biogas plant (picture by Tauno Trink).

Figure 9.2. Oisu biogas plant (picture by Ahto Oja).

Figure 9.3. Vinni biogas plant (picture by Ain Liiva).

9.3.3 Socio-economic and environmental impacts

Biogas production creates diversification of agriculture; odour-free distribution of the digestate; less pollution of soil, surface water and groundwater; less spontaneous methane emissions, lower air emissions compared to fossil fuels and a positive image of digestate as an organic fertiliser. The following outlines the potential social and environmental impacts and economical business opportunities for Estonia.

Favourable conditions for the production of biogas in Estonia:

- Farms are relatively large and modern;
- Heating demand during the winter periods will allow to use at least some of the heat energy effectively;
- There is existing and quite large unused potential of raw materials (e.g. silage from energy crops, hay from nature protection areas);
- The need for new energy capacities, i.e. energy prices reflecting the rising trend.

Unfavourable conditions for the production of biogas in Estonia:

- National support for renewable energy is relatively low;
- Climate conditions for growing energy crops (e.g. maize) are not favourable;
- Most of the farms have recently made major investments and the ability to invest in “non-core” activities is low;
- Area is quite new, and there are no clear "success stories" which to rely on.

Biogas has clear advantages compared to other renewable energy alternatives. Biogas can be used in cogeneration for producing both electricity and heat energy. Purified biogas into biomethane could replace fossil fuels in the transport sector. Biomethane can be applied for the same purposes as the natural gas and could be injected to natural gas grid.

9.3.4 Economical, employment, regional policy and business opportunities

Production of substrates, biogas production, upgrading and consumption creates jobs in rural areas. Assuming that each million normal cubic meter (Nm^3) of biomethane production and consumption gives additional two extra job sites[8] would create 576 jobs in Estonia. Cultivation of energy crops for biogas production (as of May 2013), on the non-used agricultural land (50% of this is 177 385 ha) would increase Estonian diversified rural economy. This would intensify land use and give some additional jobs, increase national competitiveness in agriculture. Competitiveness in foreign markets, however, would not change. Biogas production efficiency is higher, the more there is a balance between the different raw materials. The field of biogas is closely related to other sectors as well. It has strong and direct connections with energetics and energy policy, environmental protection, recycling, agriculture and regional development actions.

Specifically, biomethane production is associated with a number of public benefits. By driving and replacing fossil fuels with methane fuels, it lowers 12% carbon dioxide emissions compared to diesel and 25% to gasoline. Biomethane is a local resource that is not dependent on Russian imports (as natural gas) or the weather conditions (as e.g. solar and wind power). Biomethane could also replace shale electricity, shale oil and wood, which are Estonian raw materials. If biomethane is used in transport, it will replace the current 100% import of methane fuels. Biomethane consumption reduces particulate pollution from diesel engines which is 99.6%, NOx by 70%, carbon monoxide 50% and carbon dioxide by 12%[9].

Energetics and energy policy:

- Promotion of renewable energy;
- Promotion of high-efficiency cogeneration;
- Promotion of scattered energy;
- Promotion of energy security/independence (based on local substrates);
- Stable production schedule of basic energy booster (does not depend on the wind or sun)

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[8] Biometaani kasutamine Eesti gaasivõrgus. A.Oja. Eesti Arengufond. 2013

[9] Biometaani kasutamine Eesti gaasivõrgus. A.Oja. Eesti Arengufond. 2013

Environmental protection:

- Agricultural sector methane emission and the energy sector CO_2 emissions reduction;
- Reducing the use of artificial fertilisers;
- Biomethane is the only local source of renewable energy in transport sector

Recycling:

- Increase in recycling organic waste (including municipalities, industries);
- Improving sewage sludge management;

Agriculture:

- Enhanced utilisation of slurry and solid manure with improved fertilising properties;
- Growth of competitiveness/diversity through energy crops;
- Reduction of weeds and pathogens;
- Promotion of the adoption of less valuable land.

Regional development:

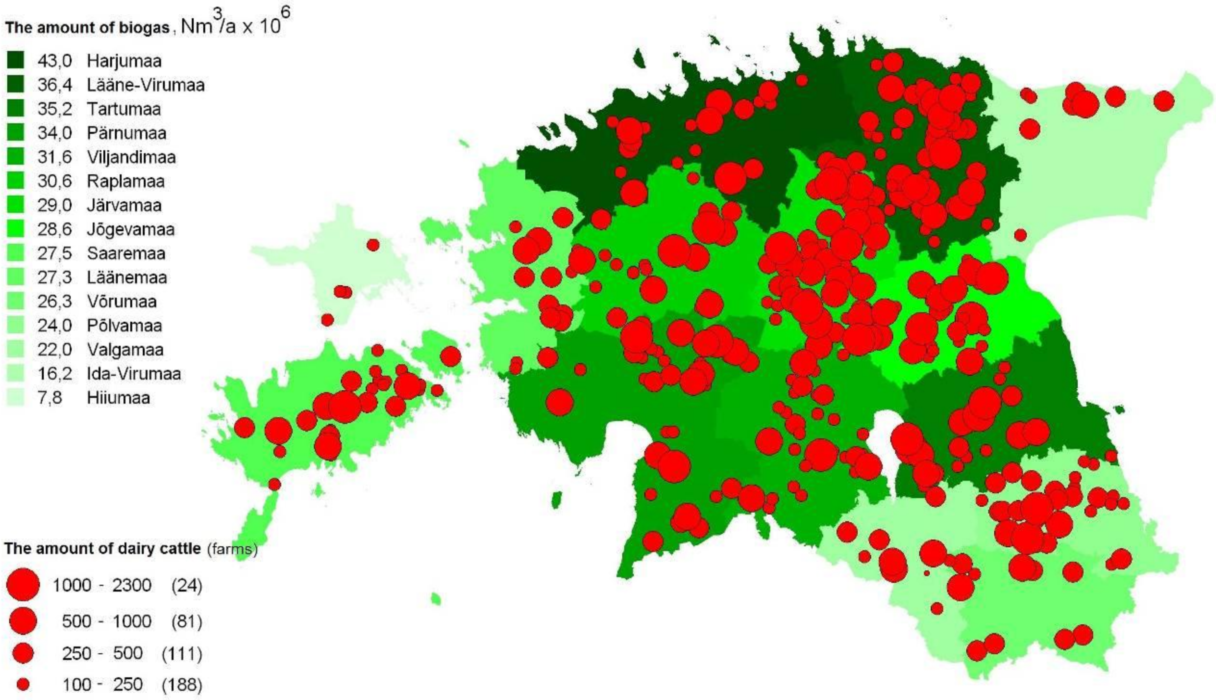
- Declined heat energy price in small villages;
- Improved living environment through reducing farm smell pollution;
- Promoted entrepreneurship in local/rural areas and employment insurance;
- Biogas can also be produced by bioenergy cooperatives, which carry several additional benefits such as increased community cohesion, autonomous energy production, resulting in increased disposable incomes for small households, etc.

In many rural areas in Estonia, the price of thermal energy is very high. Biogas plant could reduce it. This would improve the environment and help to keep/bring young people and business to rural areas. Moreover, Estonia has the capability and experience of producing the necessary partial equipment (concrete and metal constructions). In addition, electricity generator production takes also place in Estonia. Local biogas production and the production of relevant technologies gives the economy a boost and makes the foreign trade balance more positive. Also gives an opportunity to export technology.

9.3.5 GIS map of biogas potential

Figure 9.4 highlights the most promising regions in Estonia for manure energy production and provides an overview which counties have the biggest biogas production potential. Both GIS-maps include the same biogas potential based on co-substrates (reflected in green) and which is about 420 mln Nm^3 per year. County-based feasible biogas potential consists the following co-substrates: sewage sludge, biodegradable kitchen and canteen waste, oils and fats, animal waste and slaughterhouse by-products, silage (5% of usable agricultural land), silage (20% from unused agricultural land) and hay from nature protection areas.

The techno-economical biogas potential of cattle and pig manures (cattle and pig farms highlighted in red dots; Figure 9.4) is approximately 60 mln Nm^3 per year. The range of cattle and pig farm size is quite wide, from 100 up to 2300 of cattle and from 100 up to almost 60 000 of pigs.



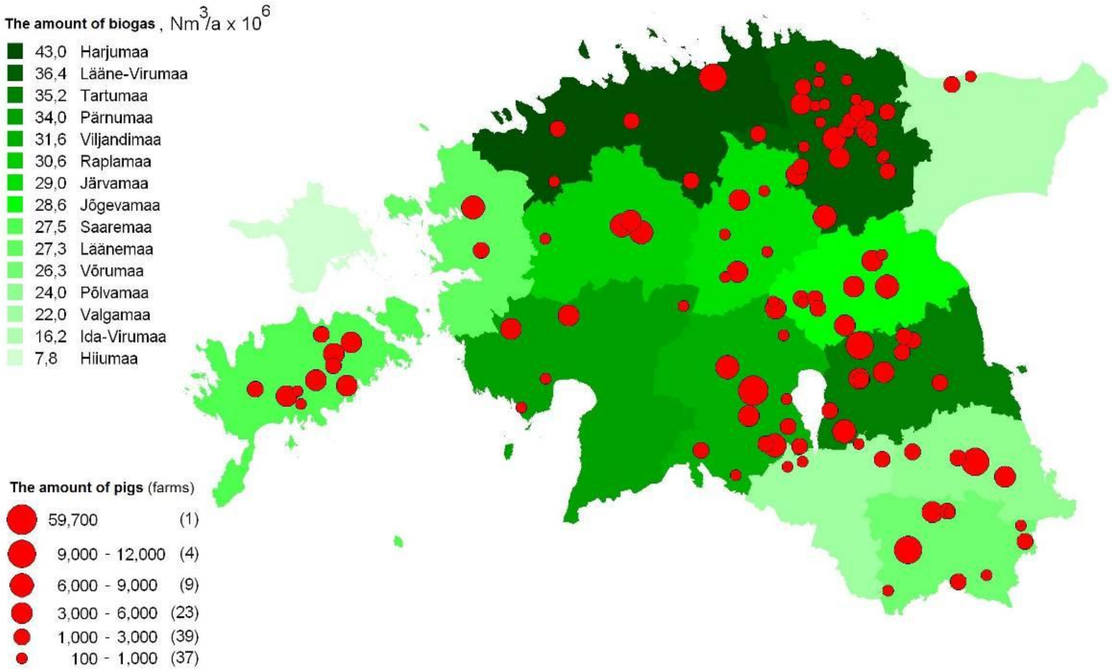


Figure 9.4. GIS-map of Estonian biogas techno-economical potential based on co-substrates. The techno-economical energy potential of manures (cattle, pig) leaves out all manure produced on farms (brought out/outlined as hot red spots) with less than 100 animals. The upper figure represents cattle farm locations by size and lower figure represents pig farm locations by size.

The total (including manure techno-economical potential) yearly feasible biogas resource is estimated to be 480 million Nm³/a in Estonia. Taking into account the average investment cost of agricultural biogas, it can be argued that the implementation of feasible biogas potential (480 million Nm³/a, with electrical nominal power N_{el} = 118 MW) for local biogas sector development and energy security would cost approximately 672.6 million € in case 30% of biogas potential (35.4 MW) is produced as heat and electricity (CHP) and 70% (82.6 MW) of feasible biogas potential (167.4 ktoe) is used as motor fuel (biomethane). Based on this assumption, it could be pointed out by counties the feasible biogas production places in Estonia. Depending on biogas plant cogeneration unit (1 MW) there could be approximately 36 biogas CHP plants and 84 biomethane production plants (Figure 9.5).

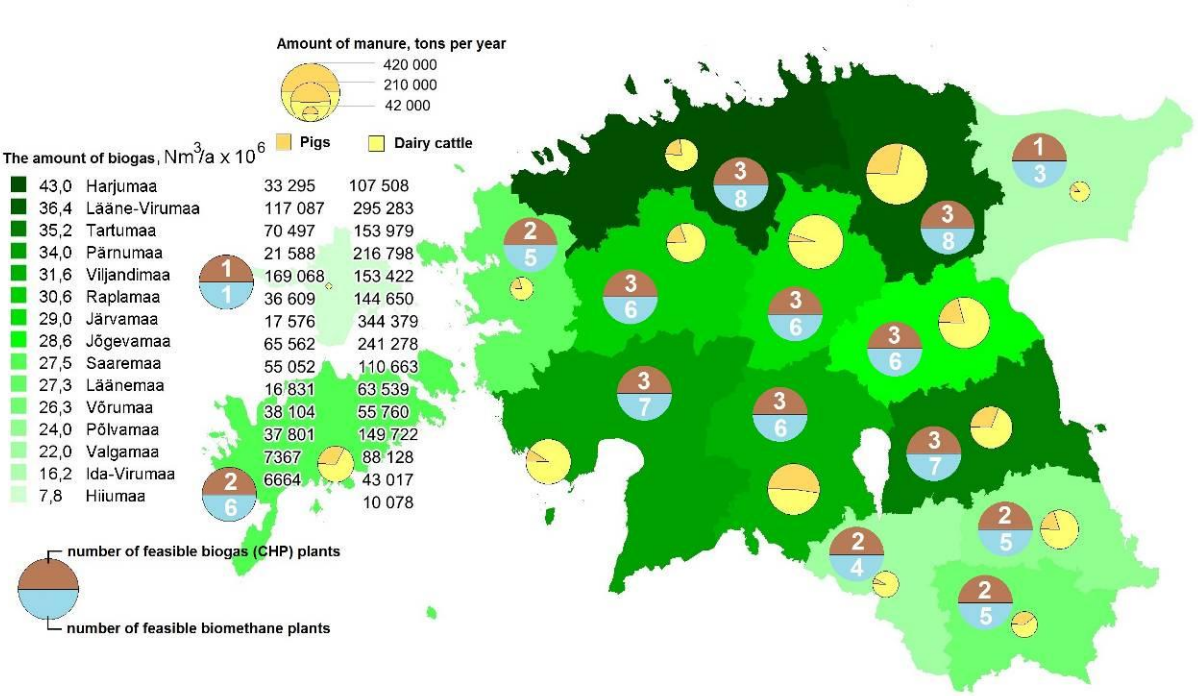


Figure 9.5. Annual amount of manure (pigs, dairy cattle), biogas techno-economical potential based on co-substrates and feasible biogas production plants (with an electrical power of 1 MW cogeneration unit capacity) in counties.

9.3.6 Impact of co-substrates

Wastes and by-products from municipalities and industries may offer energy-rich co-substrates for manure-based biogas plants, but their safety with respect to pathogens and pollutants must be carefully considered. Many wastes and by-products may require hygienisation. Mixing of manure with different co-substrates may result in process requirements from the legislation. While manure utilisation makes an exception in the animal by-product regulation of the European Commission (2009/1069/EC), mixing it with other substrates may still result in the requirement for hygienisation or sterilisation[10].

Anaerobic digestion reduces very efficiently the pathogen content in a digestate, which notably depends on the temperature. Digestate contains nitrogen, phosphorus, potassium, sulphur and trace elements which are well absorbed by plants. Non-contaminated substrates make a very valuable fertiliser. Digestate nutrient content can vary highly because it depends directly on the substrate. Compared with raw slurry, it is positive that the digestate is less viscous and therefore more rapidly absorbed into the soil and reduces emissions. After digestion, digestate is collected to storage. Newer storage facilities are all gas-securely covered to reduce methane emissions. The liquid digestate will be led with slurry spreading machinery to the field, in case of a more solid digestate manure spreaders will be used. Usually, digestate will be delivered on the field from which the substrate came. This ensures the return of nutrients in a closed circuit. When the slurry and/or solid manure is digested, weed seeds are largely obliterated (assuming about 80%) and the farmer or plant breeder will have less cost from weed control. This cost saving can be considered as a public good.

Based on recent statistics, annual Estonian average of manure amounts is totally about 3.6 million tons[11]. For instance, when the demand of manure per hectare is 30 ton/a, this amount could fertilise approximately 120 000 hectares of fields. Therefore, about 120 000 hectares does not need weed control. Interchangeable costs are the financial expenses to weed control. We assume that the average annual cost for weed control per hectare is about 50 € (this price is based on Table 9.1). Thus, the annual savings on the cost of plant protection products is about 6 million €/a.

Table 9.1. Plant protection costs per one spray €/ha in 2012 (Põllumajandusministeerium (Ministry of Agriculture) Maamajanduse infokeskus 2012. Kattetulu arvestused taime- ja loomakasvatuses, Jäneda, lk 28.)

	Price of the product €/kg; €/l	**consumption rate l/ha; kg/ha**	**Cost per one spray, €/ha**
Herbitsiid Titus	998.00	0.03	29.94
Fungitsiid Ridomil Gold MZ 68 WG	17.50	2.5	43.75
Fungitsiid Dithane NT	7.67	2.0	15.34
Fungitsiid Infinito	18.00	1.2	21.60
Insektitsiid Fastac 50	10.50	0.2	2.10
Insektitsiid Detcis Mega	22.50	0.15	3.38

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[10] Energy Potential of Manure in the Baltic Sea Region: Biogas Potential & Incentives and Barriers for Implementation, Knowledge report. Sari Luostarinen (ed.). Baltic MANURE WP6 Energy Potentials of Manure. 2013

[11] Energy Potential of Manure in the Baltic Sea Region: Biogas Potential & Incentives and Barriers for Implementation, Knowledge report. Sari Luostarinen (ed.). Baltic MANURE WP6 Energy Potentials of Manure. 2013

Scenario 1: Manure-based biogas production

In this scenario, it is assumed that biogas is produced from manure only (cattle and pig manure each about approx. 20 000 t/a), with an annual capacity of 1 000 000 Nm^3 of biogas. Additional raw materials (co-substrates) are not used. In short, the scenario name is *Biogas mini*.

Table 7.2. Biogas mini and Biogas opti scenario overview by costs and revenue.

	CAPEX / per electrical nominal capacity (kW)	CHP working hours	Electrical nominal power N_{el}	Electrical efficiency of CHP generator (38%); kWh	Feed-in tariff per kWh (inc Nordpool)	Revenue from selling renewable electricity (€)	Self-consumption of produced electricity (10% of income)	Income of selling renewable electricity
Electricity	3500	8000	287	2298240	0.095	218332.8	21 833.28	**196 499.5**
Thermal				Thermal energy efficiency of CHP generator (40 %); kWh	Self-consumption of produced thermal energy (30%); kWh	Thermal energy for sale	Income of selling thermal energy (50% of the heat is sold (district heating systems) with price of 30 € / MWh (= 3 c € / kWh)	
				2419200	725760	1693440	**25 401.6**	

With CHP production, it could be said that total annual income of selling produced electricity and thermal heat (50%) is 221 901.1 €. Following preconditions were used in calculation: electrical efficiency of the CHP generator is 38% and thermal efficiency 40%, annual biogas production (58% CH_4) 1 million Nm^3, working hours in CHP 8 000 hours/a, capital investment cost (CAPEX) 3 500 €/kW and CHP CAPEX 1 500 €/kW. Half of the produced thermal energy was sold for district heating system with the price of 30 €/MWh, biogas plant own heat consumption was 30% and operational costs (OPEX) consisted 8% from CAPEX. In this CHP scenario (Biogas mini) were two sub-scenarios (a; b), one basic with 30% investment subsidy and another without investment subsidy.

a) In terms of 30% investment subsidy, 50% of loan (period 10 years) and 50% of self-financing positive cash flow starts in 7th operating year;
b) In terms of no investment subsidy, 50% of loan (period 10 years) and 50% of self-financing positive cash flow starts in 11th operating year.

With biomethane production, it could be said that total annual income of selling produced biomethane is 226 072 €. Following preconditions were used in calculation: Annual biogas production (58% CH_4) 1 million Nm^3 (0.58 million Nm^3 upgraded biomethane 98±1 % CH_4). Capital investment cost is (CAPEX) 3 500 €/kW and biomethane production unit CAPEX 2 500 €/kW. Biomethane is sold to the grid with the price of 0.65 €/kg (without VAT). In this biomethane scenario (Biogas mini) were two sub-scenarios (a; b), one basic with 30% investment subsidy and another without investment subsidy.

a) In terms of 30% investment subsidy, 50% of loan (period 10 years) and 50% of self-financing positive cash flow starts in 9th operating year
b) In terms of no investment subsidy, 50% of loan (period 10 years) and 50% of self-financing there is no positive cash flow during the next 12 years time

Scenario 2: Manure-based biogas production including 40% of co-substrates

In this scenario, it is assumed that the biogas is produced from manure (cattle manure approx. 9.200 t/a and pig manure approx. 3.200 t/a) and additional raw materials (co-substrates: fats and oils approx. 800 t/a, biodegradable materials approx. 2.600 t/a and silage about 1.500 t/a), the annual capacity of 1 000 000 Nm^3 of biogas. Additional materials are used to the extent of 40%, which are collected in a commercially reasonable transport cost region (of 15-30 km radius). In short, the scenario name is *Biogas opti*.

With CHP production, it could figuratively be said that total annual income of selling produced electricity and thermal heat (50%) is 221 901.1 €. Following preconditions were used in calculation: electrical efficiency of CHP generator is 38% and thermal efficiency of CHP generator is 40%, annual biogas production (58% CH_4) 1 million Nm^3, working hours in CHP are 8000 hours/a, capital investment cost is (CAPEX) 3 500 €/kW and CHP CAPEX is 1 500 €/kW. Half of the produced thermal energy was sold for district heating system with the price of 30 €/MWh, biogas plant own heat consumption was 30%, operational costs (OPEX) consisted 11% from CAPEX. Price for silage 30 €/t and the cost of the slurry transport from surrounding farms is 1 €/t/km. In this CHP scenario (Biogas opti) were two sub-scenarios (a; b), one basic with 30% investment subsidy and another without investment subsidy.

a) In terms of 30% investment subsidy, 50% of loan (period 10 years) and 50% of self-financing positive cash flow starts in 12th operating year
b) In terms of no investment subsidy, 50% of loan (period 10 years) and 50% of self-financing there is no positive cash flow during the next 12 years time

With biomethane production, it could be said that total annual income of selling produced biomethane is 226 072 €. Following preconditions were used in calculation: Annual biogas production (58% CH_4) 1 million Nm^3 (0.58 million Nm^3 upgraded biomethane 98±1 % CH_4). Capital investment cost is (CAPEX) 3 500 €/kW and biomethane production unit CAPEX is 2 500 €/kW. Biomethane is sold to the grid with the price 0.65 €/kg (without VAT). In this biomethane scenario (Biogas mini) were used two sub-scenarios (a; b), one basic with 30% investment subsidy and another without investment subsidy.

a) In terms of 30% investment subsidy, 50% of loan (period 10 years) and 50% of self-financing financing there is no positive cash flow during the next 12 years time
b) In terms of no investment subsidy, 50% of loan (period 10 years) and 50% of self-financing there is no positive cash flow during the next 12 years time

9.3.7 *Policy recommendations for the use of manure as a substrate for biogas production in Estonia*

In Estonia, it is possible to learn from other countries' experiences and adapt them to the circumstances in Estonia. Estonia should continue biomethane fuel excise tax exemption and be self-initiators, partners and operators in bioenergy cooperatives. The country may be able to run local fleet (buses, tractors, trucks and cars) with a certain amount on biomethane – at the time of writing there are about 200 CNG vehicles that could run on biomethane as well. There are also favourable conditions of biomethane production in Estonia. Estonia has set a target that by 2020, 10% of transport fuel must come from renewable sources and biomethane is one of the most credible solutions. It is naturally challenging to start building the CNG/CBM infrastructure (including NGVs second market) from zero, but that is why the public sector must have a key role in supporting a pilot plant and factories to develop and provide support to the share of biofuels in transport of reaching a level that is 92 ktoe[12] by 2020.

Policy-makers could introduce the following biogas development measures to *National Renewable Energy Action Plan 2020:*

- Determine priority-supported raw material list for biogas production with clear indication to which (singly or in combination) produce acceptable digestate to be used as fertiliser;
- Develop an agreed standard of biomethane quality for biomethane injection into natural gas grid and a procedure of each parties' rights and obligations; alternatively, change natural gas quality standard so that the methane content is in the range of 95-98%;
- Offer investment support to cattle breeders for manure storage with the obligation to build biogas production and upgrading units;.
- Make urban public transport procurement conditions in tender to contribute to the transition to methane fuels[13];
- Introduce a clear legal framework for using digestate as organic fertiliser; make it cover the whole circle of all participants including investors, entrepreneurs, planners, local governments, energy companies, (food) waste and potential users / customers of digestate.
- Make a legal framework ensuring incentives and thus securing the investments in form of long-term contracts (e.g. for 15 years).
- Increase the price-support by different components in maximum up to 14 €c/kWh, additionally to Nordpool market price and introduce the fixed-price-support to biomethane 80 €c/kg.

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[12] toe - Unit representing energy generated by burning one metric ton (1000 kilograms or 2204.68 pounds) or 7.4 barrels of oil, equivalent to the energy obtained from 1270 cubic meters of natural gas or 1.4 metric tons of coal that is, 41.87 gigajoules (GJ), 39.68 million Btu (MMBtu), or 11.63 megawatt hours (MWh).
Source: http://www.businessdictionary.com/definition/tonne-of-oil-equivalent-TOE.html#ixzz1rc0su9m6

[13] Regional Biogas Development Strategy and Action Plan. Mõnus Minek SEES. 2011

9.3.8 Summary

The development of the biogas sector in Estonia is still at its infancy with regard to relevant know-how, implementation of workable solutions as well as political support. The greatest barrier to making use of this untapped energy source lies in the fact that in Estonia's present market situation, the economic profitability of utilising biogas for CHP production is low.

Although biogas production is just like any other entrepreneurial activity in energy production, it creates numerous socioeconomic public benefits above renewable energy production, namely regional development, rural employment, small entrepreneurs and start-ups, environmental protection and waste management - all of which are issues that are more or less dependent on outside structural support.

The experience of foreign nations may prove useful with regard to garnering political support. This includes lessons such as implementing zero excise duties for renewable fuels (and holding this status for an extended period of time), setting up investment support in conjunction with national procurement priorities, including converting public transport fleets to use renewable fuels, encouraging the use of biomethane, etc. As to what are the optimal mechanisms for fostering the production, transfer, use and utilisation of renewable fuels (inc. biogas) with respect to source, location and size of each project – this matter still needs further clarification taking into account the impact such measures will have from the economic, social, regional and environmental points of view (i.e. localised solutions).

9.4 Vision for 2025

The Baltic Manure vision 25% of all manure into biogas plants by 2025 is a very good and essential objective for Estonian biogas sector and for the state as well. Ministry of the Environment claimed in May 2013 that in the next few years time the introduction of biogas and renewable energy small solutions will be supported. The main goal concerning field of biogas is that by 2020, the use of biogas in the transport sector must replace 30.000 tons of oil use (30 ktoe).

For example, Estonia could produce about 15 million Nm^3 biogas (or approx. 8 million Nm^3 biomethane) annually if 25% of all Estonian techno-economical manure could be fermented in local biogas plants. 15 million Nm^3 biogas is approximately about 3.2% of total Estonian calculated feasible biogas potential, which indeed consists also of silage, hay from unused land, cultivated agricultural lands and semi-natural grasslands; agricultural residues; biodegradable waste from the food industry; separately collected biodegradable kitchen and canteen waste; sewage sludge and industrial waste. It is also possible to produce about 8 million Nm^3 of biomethane from this above mentioned 25% of manure target.

Following the Baltic Manure vision of 25% manure for 2025 is significantly good for Estonia, because it helps to reach the Estonian Government goal to produce 10% (92 ktoe) of total transport fuels from renewable energy sources by 2020. This clear vision could mean for Estonia that 25% of manure in biogas plants equals nearly 8 million Nm^3 biomethane which could fulfil the National Renewable Energy Action Plan 10% target of final consumption of energy from RES in transport with 0.66%.

10 Conclusions of the manure biogas scenarios

Sari Luostarinen

According to the national scenarios created and presented here, there are distinct regions of intensive animal production with subsequent high amounts of manure in all BSR countries. In Finland, the dairy production regions in the Eastern and Western Finland as well as the pig and poultry producing region of South-Western Finland could especially invest in farm co-operative, manure-based biogas production. The largest farms could build farm-scale plants as well. In Sweden most of the manure is in the Southern regions, while in Denmark manure is available for biogas production basically all over the country. The German states of MV and SH, the animal density of SH is higher, thus with more manure, but on smaller farms. In MV the animal density is lower, but manure amounts still significant and located in fewer, larger farms. In Poland, the amount of manure available is the highest for BSR and the density of animal production is the highest in the Mid-West. The manure in Lithuania is spread across the country rather evenly, while in Latvia animal production is heavily concentrated on only certain regions which subsequently hold the most significant manure energy potential. In Estonia much of the animal production and thus manure is located in the northern regions on the coastline to the Baltic Sea and further South around the cities of Tartu, Pärnu and Viljandi.

In all BSR countries, solid manures hold a significant portion of the techno-economical energy potential of manure. Therefore, solutions for digestion of solid manure (and other lignocellulosic materials) are needed, but the requirement varies between the countries. For instance in Denmark, approx. 80% of all manure is slurry and thus solid manure could easily be directed to slurry-based biogas plants using the conventional CSTR technologies. However, in Poland 90-95% of all manure is solid and feasible, efficient technologies for sole digestion of solid manure are needed. This issue is dealt with in detail in the last chapters of this report.

In order to harness the energy potential of the manure, different solutions and plant scales were considered depending on the national conditions in the BSR countries. All countries find that all different scales, from single farm to large biogas plants, are needed when attempting to harness manure energy potential as biogas. The amount of potential biogas plants to be built totalled to hundreds per country, and thus thousands per BSR, depending on the different example-wise scenarios created. Subsequently, the investment cost estimated becomes substantial. This is expected to create significant business opportunities within the biogas and overall manure sector for all technologies required in the manure management chain. If it is also simply assumed that all biogas plants would employ 1-2 persons, the amount of job opportunities becomes significant. It is also likely that the employment of plant designers and constructors would increase.

With co-substrates, the amount of energy produced as manure-based biogas can be significantly increased. For instance in Finland, if potential grass biomasses available would be utilised for co-digestion with manure, the manure energy potential could be increased by fivefold (from 1.4 TWh/a to 7.2 TWh/a) and the amount of 1 MW biogas plants would increase from 173 to 900. In Sweden, the use of available co-substrates would increase the annual energy production from 1.3 - 2.8 TWh/a to 2.6 - 4.1 TWh/a. The additional biogas plants to be built when adding the co-substrates would also significantly increase the money invested in biogas production and the amount of job opportunities only within the plant operation. It is again likely that the employment of plant designers and constructors would increase.

Currently, manure-based biogas is not economically feasible in any of the BSR countries. Even the most advanced manure-based biogas producers, Denmark and Germany, rely on financial incentives to increase the profitability. Especially Denmark, which aims at 50% of manure into energy (biogas) production by 2020, has released new incentives which have accelerated biogas plant projects all over the country. In most other BSR countries, profitability can currently (autumn 2013) only be met with the use of energy-rich co-substrates which either increase the energy production to profitability and/or improve the plant economy via gate fees. In Germany and Latvia, maize silage is the most used energy crop. In Poland and Lithuania, the tendency is to follow-up on the use of maize. In Denmark, on the other hand, the use of energy crops will be restricted to 12% of the feed into biogas plants. The Northern BSR countries, Sweden, Estonia and Finland are looking into grass biomasses as a potential co-substrate. All BSR countries include organic waste materials into manure-based biogas production.

It is apparent that financial incentives are still to be created, improved and implemented in the entire BSR in order to promote manure-based biogas and to direct the practical solutions into best possible combinations of the complex decisions to be made. Moreover, clear targets for and stable regulation of manure-based biogas should be implemented in order to push investments forward.

Still, the Baltic Manure Vision of having 25% of all manure in the BSR directed to biogas production by 2025 is not a totally idealistic target. In the German states of SH and MV, it is already done. Denmark is approaching the goal. Latvia has the capacity ready if only more manure would be digested in the existing biogas plants. For Finland and Estonia, the target is feasible if the political push and subsequently incentives are sufficient to advance manure biogas with stronger measures than currently. For Lithuania, the vision is too ambitious owing already to the fact that currently there are no biogas plants digesting manure, while for Poland to reach the target, improved solutions for digesting solid manure are vital.

All in all, the Baltic Manure Vision for manure-based biogas shows that the targets set assist in making the desired changes in manure management as it forces to find true solutions for reaching the target, instead of beautiful words and little action. A similar effect can be seen for the national scenarios for manure-based biogas. Although the scenarios presented in this report are only rough estimates, give some examples of how manure could be directed into biogas production and what this might mean in practise in the BSR, they already offer clear indications as to what kind of action and where should be taken in order to promote manure-based biogas. Therefore, it is recommendable to set ambitious targets and truly study the possibilities of how to reach them.

11 Best practices for manure-based biogas in the BSR

11.1 Introduction

During the course of the project Baltic Manure and the work into solutions for manure energy use, a few things kept popping up as significant for truly harnessing the manure energy potential in the BSR as biogas and to ensure that the practices applied are the best possible for the environment.

There is a lot of solid manure in the BSR and the current technologies available for digestion of solid manure are not sufficiently efficient when it comes to energy yield, digestate quality and emission mitigation. There is a great need for developing solid manure digestion and Baltic Manure recommends the following steps forward:

- Promote co-digestion of solid manure and slurry.
- Develop and implement pre-treatments to enable improved degradation of and thus energy yield from solid manure.
- Improve dry fermentation technologies.

Monodigestion of slurry (i.e. digestion of slurry alone) needs boosting in order to improve energy yield and thus plant economy. This can be achieved with energy-rich co-substrates. Co-substrates derived from manure are the most recommendable (solid manure, separated solid fraction of slurry), though suitable wastes and by-products from municipalities and industry are also to be promoted. The use of plant biomass is an issue to consider carefully. By-products, such as grasses from natural and water protection zones, or by-products, such as straw, are recommendable, but the use of annual energy crops, such as maize, should be minimised due to their environmental concerns. The technologies for using co-substrates should also be chosen wisely, e.g. with respect to pre-treatment.

The hydraulic retention time of biogas plants should be maximised in order to increase energy yield and to minimise emissions. Biogas plants with only one digester are not recommendable. The digester should be followed by a gas-tight post-digestion tank in which the post-biogas is collected and utilised in energy production as a mix with the digester-biogas. Otherwise significant methane emissions will occur in the digestate storage. The storage should be covered in any case in order to prevent nitrogen losses via ammonia volatilisation.

In the following chapters these issues will be dealt with in more detail.

11.2 Dry fermentation for solid manure

Andrea Schüch

11.2.1 Background

Depending on the physical properties of the substrate, different anaerobic digestion processes are suitable. Up to a dry matter content of 12-15%, the substrate is more suitable for wet fermentation. But when the dry content increases, dry fermentation processes may become appropriate. As well as for the wet fermentation, for the dry fermentation continuous or discontinuous (batch) processes are possible (Figure 11.1).

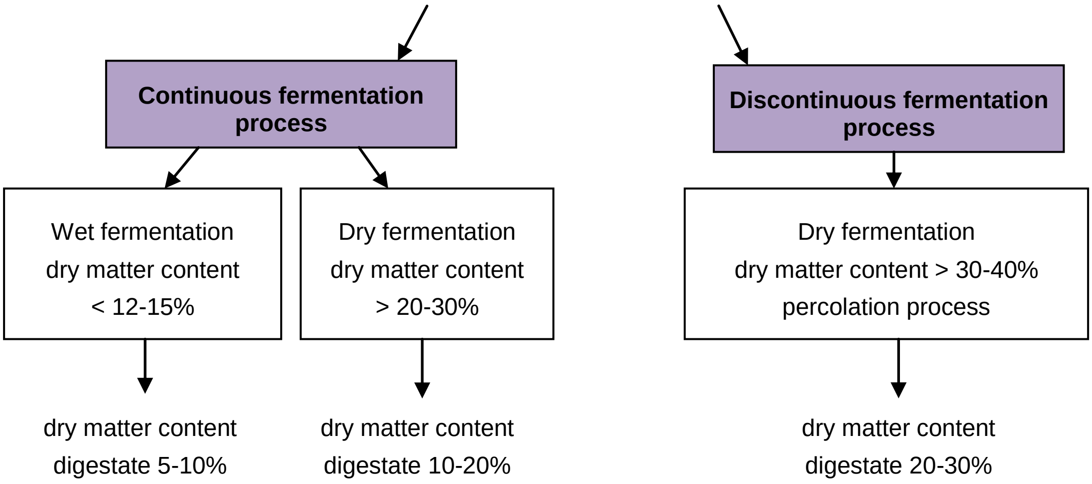

Figure 11.1. Continuous and discontinuous fermentation processes

One crucial advantage of the dry fermentation technology is that the substrates with a high solid content, like solid manure, can be used with a marginal pre-treatment. Often even pulping is not needed. Typically the energy demand is lower as for the wet fermentation. Caused by the construction there are no problems with a formation of foam or layers in the digester. Furthermore they are relatively resistant to malfunctions and abrasion. Digester volume is also reduced. The disadvantage is that the specific biogas and methane yield can be lower than by using wet fermentation, caused by the lesser pre-treatment and also technical challenges with mixing.

Ecological aspects of the anaerobic digestion processes are shown in

Table 11.6. The most significant advantage of dry fermentation over wet processes is that the digestate with its higher solid content can contribute to the humus reproduction and that the conditioned digestate can substitute peat, for instance when it is used in horticulture or for gardening.

Table 11.6. Ecological aspects of composting and anaerobic digestion (Source: BMU 2009, adapted).

Recovery routes	**Composting**	**Anaerobic digestion**	
Product	**material -solid-**	**energetic/material -solid/dry-**	**energetic/material -wet-**
Humus reproduction	+++	+++*	0
Peat substitution	++	++	0
Plant nutrients			
- nitrogen	+	+	++
- phosphorus	++	++	++
- other nutrients	+	++	++
Energy: power, heat	(+)	++	+++

*The more +, the more positive is the process for the recovery route.

As explained the dry fermentation process is ideally suited especially for solid manure. But this technology has its pros and cons, as shown in the following lists:

<u>Pros of the dry fermentation:</u>

- for substrate with high dry matter content
- no pulping, only marginal pre-crushing needed
- lower energy consumption (minimal pumping and mixing, low heat demand)
- small digester volume possible
- little foaming and lamination
- less sensitive to impurity (incl. sand), less abrasion
- continuous operation possible
- low concentration of hydrogen sulfide in biogas
- storage of liquid digestate unnecessary

<u>Cons of the dry fermentation:</u>

- less gas yield due to lower degradation
- partially reduced gas discharge by zoning due to the missing circulation
- difficult nutrient supply to microbes due to lower lower water and mixing
- huge amount of inoculum necessary to retain the active biological process
- lower energy output
- expenditure for safety features and equipment

11.2.2 Dry fermentation processes and construction types for dry fermentation

Dry fermentation processes can be divided into continuous and discontinuous processes (Table 11.7). The most noted construction type for the discontinuous dry process is the box or garage digester. Different construction types exist for the continuous dry fermentation processes, such as vertical and horizontal digesters. In the following selected principles of this different construction types are shown and shortly explained.

Table 11.7. Differentiation and characteristics of the fermentation types

Differentiation through the dry matter content	**< 12-15%**	**> 20-30%**	**> 30-40%**
Type of fermentation	**wet**	**dry** continuous	**dry** discontinuous
Construction type	mix and circulate	plug-flow (“Pfropfenstrom”)	box digester with percolation
Range of temperature	mesophilic / thermophilic	mesophilic / thermophilic	mesophilic
Producer / company	for example: BTA, RosRoca	for example: Kompogas, Dranco, Strabag	for example: BEKON, bioferm, Loock, Eggersmann
Digestate	liquid	solid-liquid-separation needed for stackable digestate	solid / stackable

Discontinuous process – Box / garage fermentation

Box or garage digesters can be constructed of steel or concrete. The construction and operation of the gas tight gate requires special diligence. Depending on the substrate and used filling technique, only 2/3 of the digester volume could be used for the substrate (Biogashandbuch 2007).

For the batch operation required, it is necessary to empty and fill the stackable substrate in the digester. The substrate is firstly mixed with the digestate from a former batch in order to start the biological process. The percolate circulates in the system (Figure 11.2). The heating system could be installed directly in the digester walls or in the percolate tank. To produce a relatively constant biogas flow, several boxes can be run in a line, as shown in Figure 11.3.

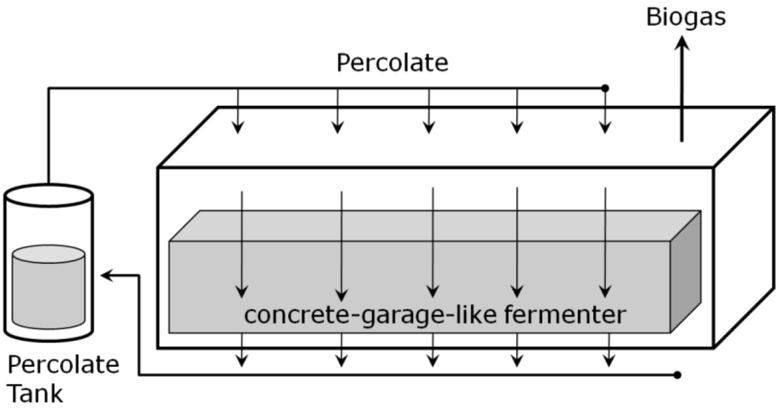

Figure 11.2. Principle of the box fermentation process (Mata-Alvarez 2003).

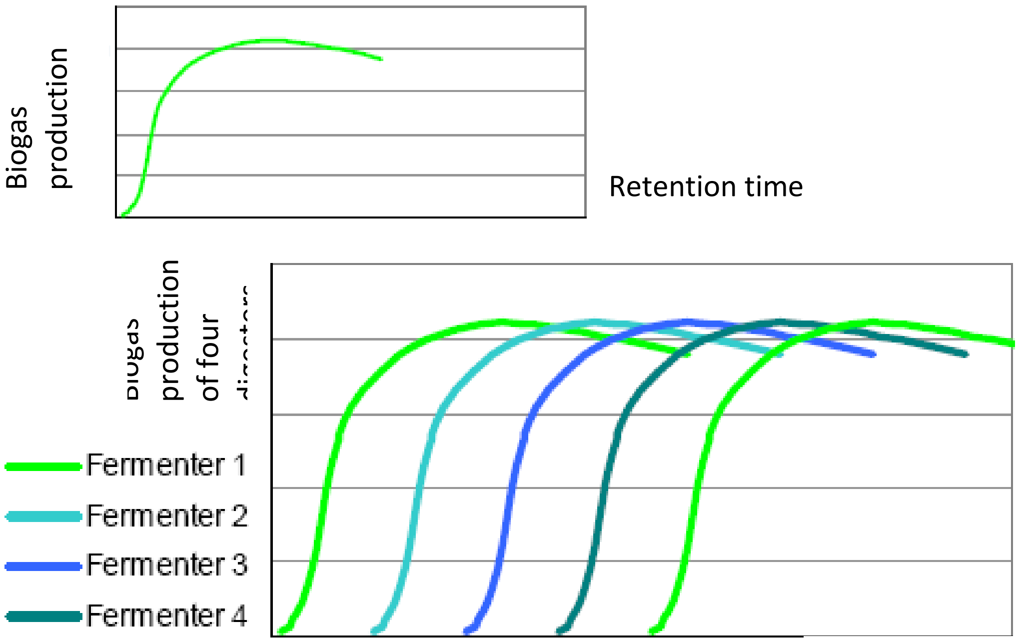

Figure 11.3. Continuous gas yield by time-shift operation of several digesters (fermentors).

Continuous dry fermentation processes

A horizontal digester can be made of concrete or steel. Concrete digesters have a quadratic or rectangular profile and a volume from 250 to 1000 m³ and a maximum length of 25 meter (Figure 11.4). Steel-made digesters have ordinarily a circular profile with a maximum volume of 270 m³ with 24 meter length (Biogashandbuch 2007).

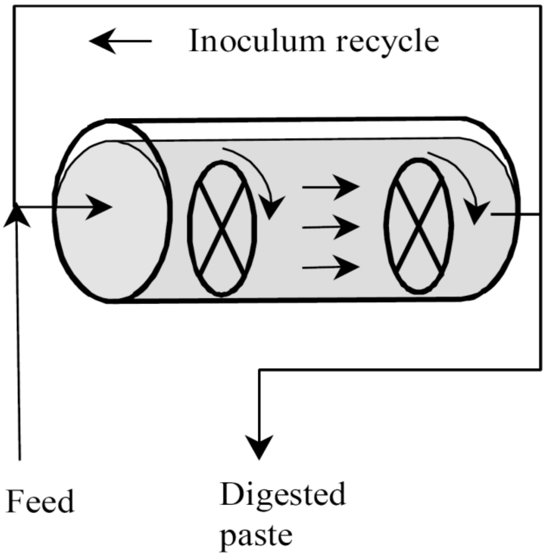

Figure 11.4. Principle of the horizontal plug-flow digester (Mata-Alvarez 2003).

In a horizontal plug-flow process called "Pfropfenstrom", the substrate is continuously mixed and passes through the digester in a perfusion (Figure 11.4). Different zones of anaerobic degradation evolve in the digester. The average retention time corresponds to the speed of the plug-flow and is limited by the growth rate of the microorganisms.

Examples for vertical digesters are shown in Figure 11.5. Here the substrate passes the vertical digesters continuously, but without mechanical mixing. In the left figure, the substrate passes the digester by "falling", in the right it circulates around a vertical wall and is "aerated" with recirculated biogas.

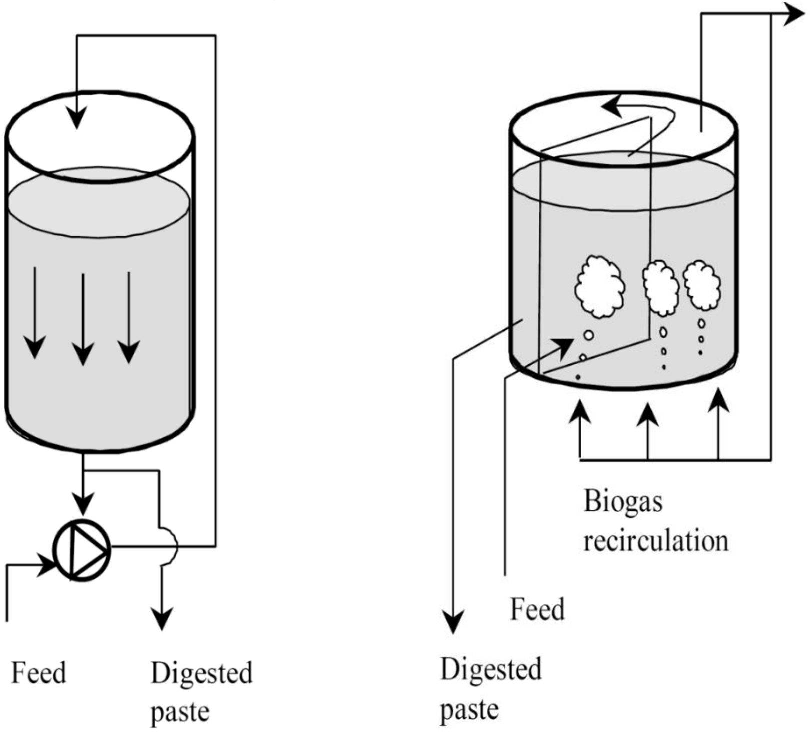

Figure 5: Principles of vertical digesters, left: Dranco, right: Valorga (Mata-Alvarez 2003).

11.2.3 Emissions

It is important to avoid or limit the greenhouse gas emissions when running a biogas process. Greenhouse gas emissions are direct or indirect. Data for emissions from existing biogas plants is unavailable, but some studies for different emission sources are known (Table 11.8).

Table 11.8. Overview to available literature and data to emissions from biogas production (without digestate distribution; UROS 2007).

Process action	Remark	Data
Ensilage / storage	Emissions while ensilage/ removal	No data, Estimation: 5-20 % silage mass loss (degradation)
Mixing tank	Usually open tank, mixed (ammonia, methane and nitrous oxide)	No data
Digester	Incl. CHP and gas cleaning	1.8 % methane loss (Olesen 2004; ELTRA 2003)
Digestate storage	- Open storage	- Up to 10 % (IPCC 2000), for slurry (digestate) up to 20 % methane loss without post-digestion
	- Chopped straw cover of open tanks: higher nitrous oxide, lower ammonia emissions	- Emission factors reported but controversial discussion (Amon et al. 2004, Kryvoruchko 2004, DBU 2006)

The emissions from ensilage and storage and biogas production for wet and dry fermentation are in principle the same (UROS 2007). Differences in these technologies appear due to choices in substrate pre-treatment, feeding/withdrawal and handling and storage of the digestate. For dry fermentation, especially the following is to be noted:

Pre-treatment:	The substrate/manure may be pre-rotted before filling into the garage to reduce the energy demand for heating, CO_2 is emitted during the air supply.
Filling:	Higher emissions from open mixing tanks for mixing with the inoculative digestate
Withdrawal:	Before emptying discontinuously running processes (garage/box digesters), the digester is aerated and the extracted air cleaned via biofilter. However, methane cannot be removed (Kern et al. 2010). The estimated methane loss while emptying is < 0.5 % of the methane production (UROS 2007), though the low methane potential of the digestate used as inoculum may decrease these emissions (long retention time).
Digestate storage:	The solid digestate is stored on a water-tight, open area and composts sponatenously. Compared with an open storage of wet digestate without post-digestion lower methane emissions are expected (UROS 2007). Composting may cause ammonia emissions.

Also the conversion of biogas to power and heat (CHP) causes emissions. Different studies report methane emissions of 10 to 40 g $CO_{2\ eq}/kWh_{el}$ = methane loss of 0.017 to 1.4 % of the methane input depending on the CHP technology (Bayrische Landesanstalt für Landwirtschaft 2007/2008, Bayrisches Landesamt für Umwelt 2006, DBU 2006, Wosee-Gallasch et al. 2007).

Up to now the emissions of wet and dry fermentation technologies are badly quantifiable. It depends from many factors and varies greatly. An accurate process control and a careful handling of substrates and digestate reduce the emissions (see also the chapter on pot-digestion).

11.2.4 Examples for running dry fermentation plants in Germany

Vertical steel digester, biogas plant number 49 (FNR 2009)

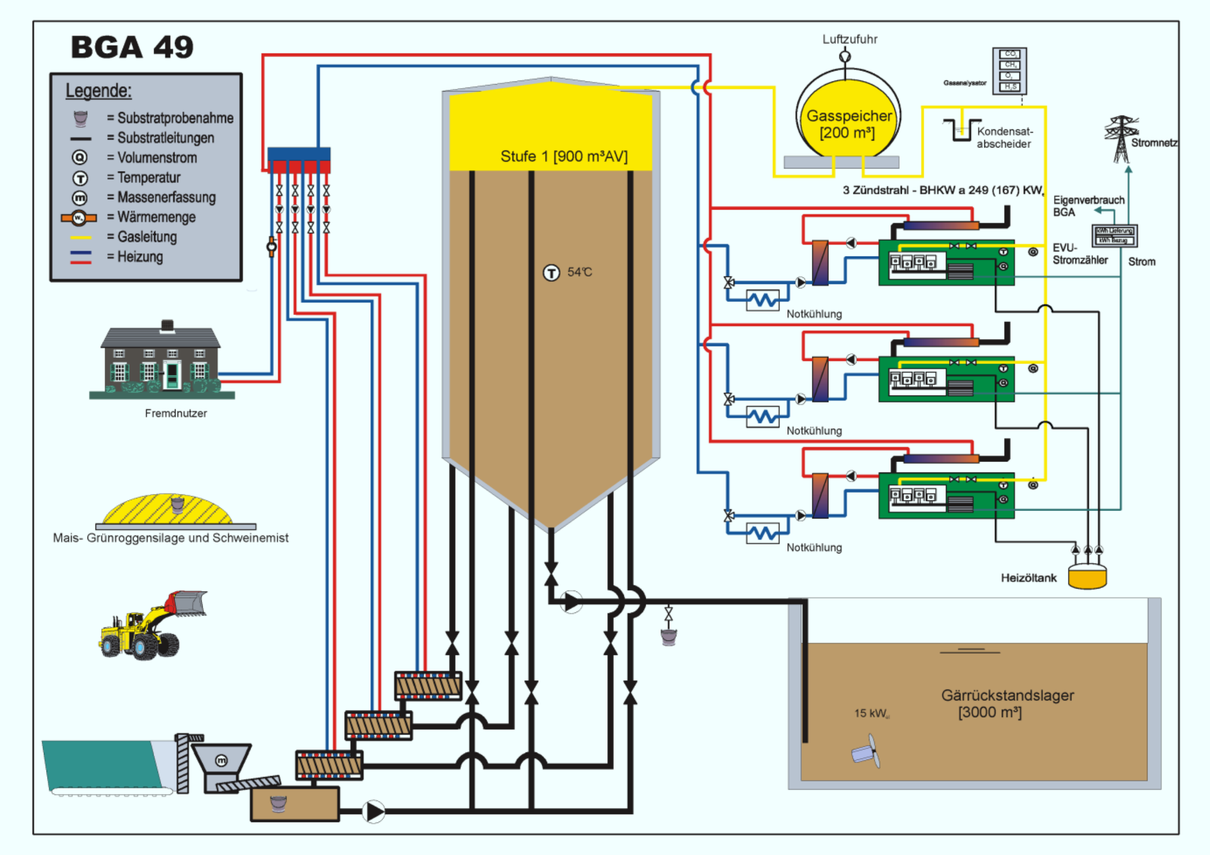

Figure 11.6. Process flow diagram of BGP 49 (Source: FNR 2009).

CHP:	3 CHP á 167 kW_{el}, total 501 kW_{el}
Substrate input per year:	10,651 tons FM
Substrate composition:	
Maize silage:	49.3 %
Rye whole plant silage:	14.2 %
Sunflowers:	13.0 %
Barley whole plant silage:	10.0 %
Solid pig manure:	6.6 %
Grass silage:	6.2 %
Solid cattle manure:	0.7 %

Biogas yield: 168 Nm^3 BG/t FM or 86 Nm^3 CH_4/t FM (605 Nm^3 BG/t VS or 313 CH_4/tVS)
Biogas quality: 50.7 Vol% CH_4; 135 ppm H_2S

Figure 11.7. BGP 49, in front the feeder for solids, behind the vertical digester, besides the operations and farm buildings (Source: FNR 2009).

Plug-flow digester, biogas plant number 53 (FNR 2009)

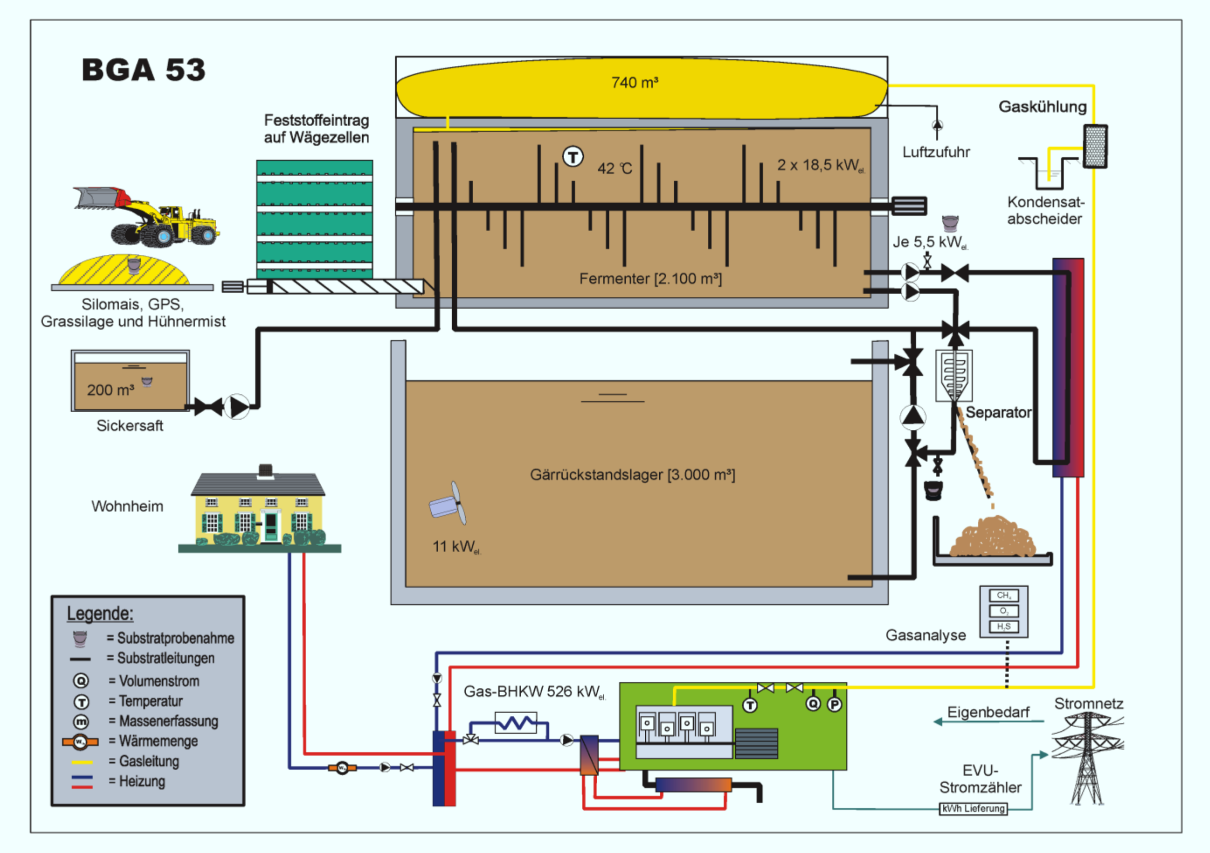

Figure 11.8. Process flow diagram of BGP 53 (FNR 2009).

CHP:	1 CHP a 526 kW_{el}
Substrate input per year:	10,651 tons FM
Substrate composition:	
Maize silage:	83.4 %
Rye whole plant silage:	6.2 %
Solid turkey manure:	5.4 %
Corn cob silage:	2.8 %
Wheat grain:	1.8 %
Potato:	0.3 %

Biogas yield: 236 Nm^3 BG/t FM or 122 Nm^3 CH_4/t FM (780 Nm^3 BG/tVS or 405 CH_4/tVS)
Biogas quality: 51.8 Vol% CH_4; 45 ppm H_2S

Figure 11.9. BGP 53, left: building for the CHP with gas torch, middle: gas storage, right: digestate separator (FNR 2009).

Box digester, biogas plant number 62 (FNR 2009)

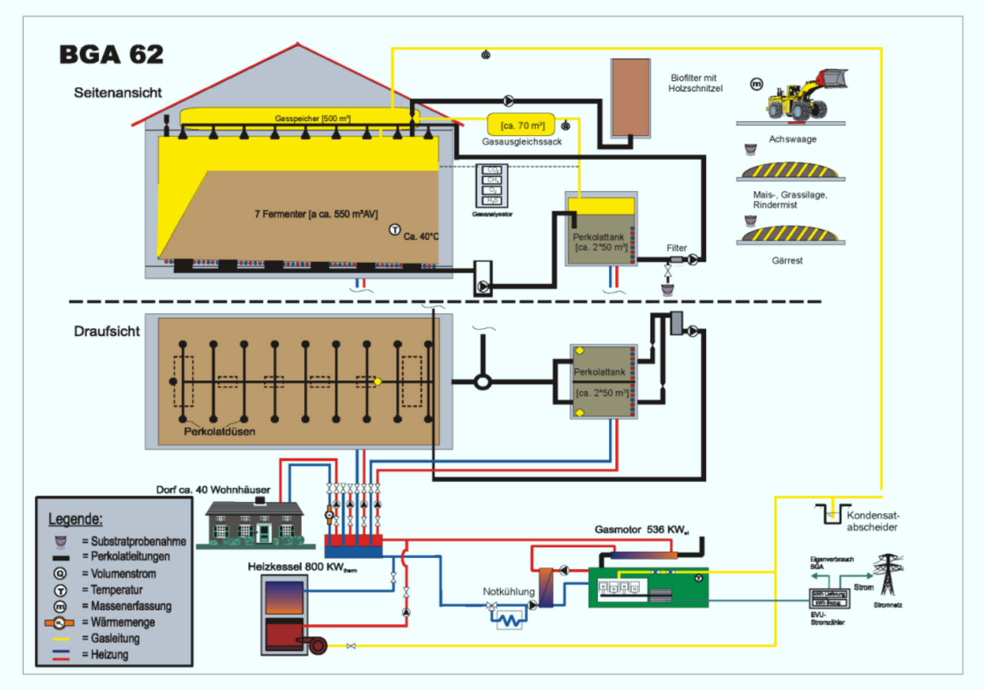

Figure 11.10. Process flow diagram of BGP 62 (Source: FNR 2009).

CHP:	1 CHP a 536 kW_{el}
Substrate input per year:	11,017 tons FM
Substrate composition:	
Maize silage:	42.7 %
Solid cattle manure:	20.4 %
Grass silage:	13.6 %
Green rye:	8.7 %
Fresh grass:	6.2 %
Sugar beet:	5.7 %
Straw:	1.7 %
Solid pig manure:	1.0 %

Biogas yield: 140 Nm^3 BG/t FM or 72 Nm^3 CH_4/t FM (528 Nm^3 BG/tVS or 273 CH_4/tVS)
Biogas quality: 53.5 Vol% CH_4; 267 ppm H_2S

Figure 11.11. BGP 62, building with seven box digesters (Source: FNR 2009).

11.2.5 Overview of producers/constructers of biogas plant

Table 11.4 is based on a review of Nichols (2004) of worldwide operating companies of the biogas sector for municipal organic waste. The technology is also suitable for solid manure and other solid biomass with high structure content. The biogas sector is dynamic and so this overview is not totally up-to-date. The number of small companies with their own development is vast.

Table 11.9. Market review (Sources: Data from the company websites as of February 2008 and adapted from Nichols (2004). In: Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste, California Environmental Protection Agency, March 2008 and own search in 10/2013)

System name	Number of plants[1]	Capacity [Mg/a]	Number of stages		Dry matter content		Process temperature	
			1	2	< 20 %	> 20 %	35 °C	55° C
AAT	8	3,000 – 55,000	x		x		x	
ArrowBio	4	90,000 – 180,000		x	x		x	
BTA	23	1,000 – 150,000	x	x	x		x	x
Biocel	1	35,000	x			**x**	x	
Biopercolat	1	100,000		x		**x**	x	
Biostab	13	10,000 – 90,000	x		x			x
DBA-Wabio	4	6,000 – 60,000	x		x		x	
DRANCO	17	3,000 – 120,000	x			**x**		x
Entec	2	40,000 – 150,000	x		x		x	
Haase	4	50,000 – 200,000		x	x		x	x
Kompogas	38	1,000 – 110,000	x			**x**		x
Linde-KCA/BRV	8	15,000 – 150,000	x	x	x	**x**	x	x
Preseco	2	24,000 – 30,000						
Schwarting-Uhde	3	25,000 – 87,600		x	x			x
Valorga	22	10,000 – 270,000	x			**x**	x	x
Waasa	10+	3,000 – 230,000	x		x		x	x
Archea			x					x
BEKON			x				x	
BIOFerm/ Viesmann			x				x	
BIOLEACHATE Process								
EnviTec			x				x	
GICON Bioenergy			x				x	
KOMPOFERM			x				x	
Loock TNS			x				x	
Schmack/SCHU BIO			x					x
Schwarting Biosystem				x			x	

[1] operating and planned biogas plants, that treat following substrates: Residual waste, Kitchen waste, food waste, organic garden or green waste, partly in co-fermentation with other organic waste or sewage sludge

11.3 Pre-treatment of solid manure and co-digestion with slurry

Mats Edström

11.3.1 Biogas potential from manure and principles for manure digestion

The techno-economical biogas potential from manure is BSR countries is 17-35 TWh/yr (Luostarinen 2013). In quantity, slurry is the major manure fraction, but it has a low energy content. Solid manure, on the other hand, has a higher energy content resulting in that it contributes with an average of 74% to the techno-economical biogas potential with a big difference between the countries (24-98%). Compared with slurry, solid manure is also richer in nutrients and its nitrogen is mostly organic bound. Digestion of solid manure has a major impact on converting the organic nitrogen into plant-available ammonium nitrogen. But a significant bottleneck for digestion of solid manure is the lack of robust, reliable and cost-effective technology. The dry fermentation processes presented in the previous chapter are in dire need of improvement.

The composition and properties of manure varies a lot both depending on livestock generating the manure and on housing system, including choice and quantity of bedding material. In general, bad quality animal feedstock is handled together with the solid manure also affecting the composition and biogas production potential of the solid manure. To describe the huge difference, three examples on manure composition are shown in Table 11.10. For instance, the nitrogen content and biogas potential are in poultry manure approx. 10 times higher than in slurry.

Table 11.10. Three example on manure composition (Edström et al. 2013a).

	Dairy cattle slurry	Poultry manure	Deep litter manure, mixture from sow and cattle	
Dry matter	8.9	66	28	% of w.w.
Total nitrogen	3.1	30	7	kg/ton
Ammonia nitrogen	1.3	4	1	kg/ton
Phosphorus	0.6	10	2	kg/ton
Potassium	3.5	19	8	kg/ton
Methane production in CSTR	Approx. 12	Approx. 127	Approx. 44	Nm^3/ton
Biogas production	Approx. 20	Approx. 210	Approx. 74	Nm^3/ton

Technology for digesting manure can be based on:

- Wet fermentation technologies like continuously stirred tank reactor (CSTR) digester. The material in the digester is slurry with slurry properties.
- Dry fermentation technologies as described in the previous chapter. The material in the digester has characters of semi-solid manure.

- Serial digestion technologies. Most common is post-digestion, but the anaerobic degradation can also be divided into two separate steps. Sometimes both steps are wet based technologies, sometimes dry and wet fermentation are combined.

11.3.2 Wet fermentation of solid manure in CSTR digesters

In general, CSTR digestion is a well-tried wet fermentation technology and it is easy to find biogas plant suppliers for it. Most biogas plants digesting manure are of the CSTR type, meaning that the dry matter content in the digester often is approx. 5% TS. Most of the feed is slurry but some co-substrates with higher dry matter content may be used. However, a significant amount of the techno- economical biogas potential of the BSR originates from solid manure. To be able to co-digest considerable amounts of e.g. deep litter manure with slurry, a pre-treatment step converting the deep litter manure into slurry may be needed before the digestion. The design of the pre-treatment step is highly dependent on the bedding material used in the housing and on the amount of stones, gravel and other external components (impurities).

Limitations

This chapter focuses only on CSTR digestion of mixtures of slurry and solid manure. The solid manure in the main focus is deep litter together with farm yard manure and the bedding material used is straw (henceforth this mixture will be called “deep litter manure”). Hence, the type of deep litter manure is principally generated by cattle, sows and horses. To facilitate digestion of solid manure in a CSTR, disintegration is crucial as a pre-treatment step. Another limitation is that technology for disintegration should be applicable on small- and medium-size biogas plants. For this reason pre-treatment technologies based on mechanical disintegration are in focus.

11.3.3 Co-substrates to improve CSTR digestion

Profitable biogas production from slurry and co-substrates

Slurry needs energy rich co-substrates for profitable biogas production. A calculation for large scale co-digestion plants in Denmark (approx. 80% of substrate as slurry; Gregersen 1998) states that the minimum biogas production required is 35 m^3 biogas/ton of substrate mixture in order to prove economical feasible (no investment grants and gate fees for reception of co-substrates included). This requirement is approx. twice the biogas production from dairy cattle or fattening pig slurry produced in a CSTR. To reach 35 m^3 biogas/ton of substrate mixture, the energy rich co-substrates must produce at least 100 m^3 biogas/ton.

Based on this biogas production for economically feasible operation, the amount of solid manure required in addition to slurry to reach this biogas production can be estimated as follows:

a) 9% poultry manure in to the slurry (Table 11.10); or
b) 32% deep litter manure in to the slurry.

This results in that 56-65% of the total biogas production originates from the solid manure and by that it becomes the main substrate in the biogas plant (Table 11.11). The dry matter content in the digester will be approx. 10% and it will have a high concentration of fibrous material.

Table 11.11. Co-digestion of slurry and solid manure in manure mixtures generates 35 m^3 biogas/ton. The composition of the poultry and deep litter manure together with slurry is described in Table 11.10.

Co-digestion, cattle slurry and:	A) Poultry manure	B) Deep litter manure	
Share of solid manure [1)]	9%	32%	of manure mixture
Share of slurry [1)]	91%	68%	of manure mixture
Solid manures share to total biogas production	56%	65%	of weight
DM content in digester [2)]	9%	10%	of weight
Ammonia nitrogen in digester [2)]	3.7	2.1	g/l
Biogas production	35	35	m^3/ton manure mixture

1) Share of solid manure (poultry manure with 66% DM or deep litter manure with straw as bedding material with 28% DM) if biogas production from manure mixture should be approx. 35 m^3/ton. The biogas production from slurry is assumed to be 17 m^3/ton.
2) Calculated ammonia and dry matter content in digester.

11.3.4 *Experiences from co-digestion of slurry together with poultry manure or deep litter manure*

In Sweden, a project on co-digesting cattle slurry and solid manure has recently been finished (2013). The project has shown that it is possible to use solid manure as a co-substrate for slurry in order to increase the biogas production from the manure mixture close to the 35 m^3/ton using deep litter manure and significantly exceed this production using poultry manure (Edström et al. 2013a). The result was accomplished both at a farm-scale plant and in laboratory. The conclusion was that:

- 10-20% addition of poultry manure resulted in 38-58 m^3 biogas/ton manure mixture (Table 11.12). The main challenge with this mixture was the high nitrogen content in the manure mixture which caused inhibition and resulted in unstable degradation process. When ammonium nitrogen level exceeded 4 g NH_4-N/l (organic load 4 kgVS/m^3 day), the specific methane production was reduced with more than 40% (Edström et al. 2013b). The reason was probably a combination of high ammonia levels and limitations in available trace metals, causing an inhibition in microbial/enzyme systems responsible for hydrolysing the organic material. Taking measures to neutralise the inhibition resulted in regained specific methane production and in increased amount of poultry manure in the feed and the ammonium level ultimately exceeded 5 g/l (organic load 5.3 kgVS/m^3 day). Initially, poultry manure also caused foaming in the digester and to control it, a surface active agent was added.
- 23% addition of deep litter manure resulted in 32 m^3 biogas/ton manure mixture. The main challenges with this mixture are 1) to design a robust and cost-effective pre-treatment step

for disintegration of the fibrous material in the solid manure and 2) to guarantee that the digester is continuously stirred due to increased dry matter content and fibrous material causing high viscosity in the digester slurry (Edström et al. 2013a).

Table 11.12. Results from co-digestion of liquid cattle manure and solid manure (Edström et al. 2013a, Edström et al. 2013b). The composition of the poultry and deep litter manure together with slurry is described in Table 11.10.

Solid manure	Poultry manure	Deep litter	
Solid manure on farm [1]	14%	23% [2]	of manure mixture
Solid manure in laboratory [3]	10-20%	-	of manure mixture
Biogas production in test [1 & 3]	38[1] – 58[3]	32	m3/ton manure mixture
Solid manure contribution to biogas production	75%	55% [2]	of total biogas production

1) Results from Edström et al. (2013a) accomplished in farm-scale biogas plant in mesophilic temperature range with 260 m^3 digester (slurry volume).
2) Calculated number compensating for using slurry with low dry matter content in practical experience.
3) Results from Edström et al. (2013b) accomplished in laboratory-scale test in mesophilic temperature range in CSTR digesters with 5 l slurry volume. Instability in digestion process occurred when the share of poultry manure exceeded approx. 15% probably due to ammonia inhibition.

11.3.5 Parameters affecting plant economy connected to disintegration

Investigations studying the effects of disintegration have usually focused only on improved specific methane production. Technologies for disintegration of solid manure should comply with more requirements, for being economical feasible as:

- Robust and minimal risk for disturbances in operation.
- Low cost for maintenance.
- Facilitate the use of CSTR even with a high share of solid manure in the manure mixture.
- Minimal risk for obstructions in pipes including heat-exchangers and outlet from digester.
- Reasonable investment cost.
- Low demand for electricity.
- Improving specific methane production due to increased specific surface area.
- Low risk for problems during 1) digestate storage, 2) spreading with slurry tanker with trailing hoses (band spreader).

11.3.6 Disintegration of lingocellulosic material for improved degradation

The organic material in manure is rich of lignocellulose. Lignocellulose builds up the structure (fibres) in plant material and includes cellulose, hemicellulose, lignin, extractives and several inorganic materials (Sjöström 1993). The inner parts of the plant fibre consist of cellulose which is attached to other cellulose by hemicellulose. Lignin, on the other hand, is a complex molecule and particularly difficult to biodegrade. It covers the cellulose fibres, hence also preventing degradation of cellulose and hemicellulose (Taherzadeh & Karimi 2008).

To increase the rate of degradation in biogas processes, lignocellulose-rich substrate has to be disintegrated before digestion. Disintegration methods can overall be divided into physical, chemical, biological and thermal methods, and they can be combined together to further improve the degradation. Disintegration of lignocellulosic substrates can result in a change of molecule structure and an increase in accessible surface area and it can remove barriers generated by lignin and hemicellulose. Disintegration facilitates enzymatic degradation of lignocellulose (hydrolysis) resulting in improved biogas production (Taherzadeh & Karimi 2008, Bochman et al. 2013). A consideration, when choosing pre-treatment technology, is that some intense disintegration technologies may also generate compounds which cause inhibition of the digestion process. This may not be noticed in batch digestion test when the potential biogas production is determined.

Mechanical disintegration increases the specific surface area of the substrate mfor enzymatic degradation (hydrolysis). The specific surface area includes both external and internal area. The external area is dependent on particle size and shape while the internal area is related to the capillary structure of the cellulosic fibre (Taherzadeh & Karimi 2008). According to Kratky & Jirout (2013), the particle size has to be reduced considerably, down to 1 -2 mm, to facilitate an effective hydrolysis of lignocellulose.

11.3.7 Principles for mechanical disintegration

Disintegration can be accomplish by one step or divided into several steps at a biogas plant. It is difficult to reach a sufficiently small particle size to facilitate effective hydrolysis just by one step disintegration (Kratky & Jirout 2013). Further on, the disintegration technologies can be divided into liquid and solid based systems.

Liquid based disintegration

Solid manure can be disintegrated with liquid technologies, for example with chopping pumps, macerators, one/twin shaft grinders or disc mills. To facilitate liquid based disintegration, significant amounts of diluting liquid has to be added to the solid manure and mixed into slurry before the disintegration step. Fresh water can be used as diluting liquid but this has considerable disadvantages due to increased volume, such as increased cost for handling digestate, higher demand for heating and short retention time in the digester resulting in low volumetric biogas production (m^3 biogas/m^3 digester volume and day). A way to minimise the digestate production, heating demand and to facilitate high volumetric biogas production is to use sludge from a CSTR digester for dilution. Consequences for the digester is long hydraulic retention time, increasing concentration of dry matter content in the digester and higher concentration of ions that might cause inhibition of the digester process.

Advantages

Solid manure contains notable amounts of sand, smaller and larger stones and metals. These objects can cause considerable maintenance requirements and reduce the capacity of the biogas plant due to building up sediment in the digester. The sediment needs to be removed by emptying the digester which obviously is a large operation. This also influences the plant economy very negatively. Separation of these hard objects by gravitation, in a pre-mixing tank between solid manure and the used liquid before disintegration, might be possible. Separation of sand, smaller and larger stones is desirable also for reducing maintenance needs at the disintegration unit and time with disturbance in the operation of the plant.

Mixing solid manure with a liquid will probably lead to that liquid penetrates into the lignocellulose fibres, giving the fibre a density closer to the density of slurry in the digester, before entering the digester. This will probably lead to the desirable effect of less formation of surface crust in the digester.

Disadvantages

The energy demand for disintegration increases when the dry matter content of the substrate decreases (Miao et al. 2011, Kratky & Jirout 2013). An example of the energy requirement for converting deep litter manure into a pumpable slurry with a combined chopping and stirring pump (first disintegration step generated a slurry with long fibres) working together with a twin shaft grinder (second disintegration step) amounts to 0.11-0.16 kWh/kg DM deep litter (Table 11.16). The twin shaft grinder used about 20-30% of the electricity required (Edström et al. 2013a) and the particle size after the conversion is shown in Figure 11.12. The particles were washed and separated by multiple sieves into three particle sizes.

Slurry produced with a chopping pump combined with a twin shaft grinder. Fibres divided into 3 sizes.

Figure 11.12. Particles from converted deep litter manure into a pumpable slurry.

Hartmann et al. (2000) reported experiences with disintegration of slurry with macerators at Danish biogas plants. With an assumption that the slurry has a DM content of 5%, the energy requirement for maceration can be calculated to 0.002 – 0.026 kWh/kg DM (Table 11.16).

Edström et al. (2005) reported experiences with disintegration tests at a farm-scale biogas plant when mixing A) ley crop silage (28% w.w.) with digester slurry (72% w.w.) and B) ley crop silage (25% w.w.), horse manure (11% w.w.) and digester slurry (64% w.w.), with a macerator. The energy requirement was:

- 0.016 kWh/kg DM ley crop (0.0363 kWh/kg DM for total system also including electricity to mixing the tank and to pump produced slurry, see Table 11.16) when the DM content in the mixture was 5.7% (excluding contribution from DM in digester slurry).
- 0.0315 kWh/kg DM ley crop and horse manure (0.0626 kWh/kg DM for total system also including electricity to mixing the tank and to pump produced slurry, see Table 11.16) when the DM content in the mixture was 6.9% (excluding contribution from DM in digester slurry).

Lindmark et al. (2012) also reported experiences with disintegration of the lignocellulose-rich ley crop silage diluted with liquid into a suspension with 7% DM. Two different high shear machines (rotor disc) were tested. There was a big difference for the energy requirement, just for disintegration, between the machines. One machine needed 0.02 kWh/kg DM, the other 0.18 kWh/kg DM (Table 11.15). Both machines disintegrated the ley crop into small particles; more than 50% of the particles were with a size smaller than 0.125 mm.

Solid based disintegration

Solid manure can also be disintegrated with solid based technologies, for example shredder, hammer mill, chain mill, extruder or knife mill. To facilitate solid based disintegration, it is important to have an accurate feeding of the machine adjusted to the capacity.

Advantages

It is easier to facilitate a high volumetric biogas production when a solid disintegration technique is used, due to no need for a diluting liquid. Still, also techniques with solid based disintegration are sensitive to sand, stones and metals that occur in solid manure, but some techniques are rather robust.

In general, the energy requirement for disintegration with solid based disintegration is considered to be lower as explained in the following examples:

- **Hammer mill;** Based on information from energy requirement from Huning (manufacturer) disintegrating ley crop silage (44-57 %DM) can be calculated to 0.014 kWh/kg DM and that for solid manure from sows (33% DM) 0.018 kWh/kg DM (Table 11.15).
- **Extruder;** Based on Bolduan et al. (2011) and Lyngsø et al. (2012) the energy requirement for disintegrating “Roadside grass cuttings” (17% DM) can be calculated to 0.009 kWh/kg DM and that for solid manure from sows (45% to 25% DM) 0.024 – 0.044 kWh/kg DM (Table 11.15). Further on Menardo et al. (2013) concluded disintegrating ley ryegrass silage (35.6% DM) can be calculated to consuming 0.035 kWh/kg DM and maize silage (36.1% DM) to consuming 0.027 kWh/kg DM (Table 6).
- **Chain mill;** Based on Jungbluth et al. (2013), the energy requirement for disintegrating horse manure (approx. 30% DM) can be calculated to 0.033 kWh/kg DM (Table 11.15).

- **Knife mill (meat mincer);** according to Nordberg et al. (1997) the particle size of silage could be reduced by using perforated steel with smaller hollows, but then the energy requirement for disintegrating will increase. Energy for mincing ley crop silage (37% DM) using a 9.5 mm hollow steel plate was 0.065 kWh/kg DM and could be reduced to 0.030 kWh/kg DM by using a steel plate with five spokes (Table 11.16).

Disadvantages

Apparently the reduction of fibre length is rather poor when hammer mill or chan mill is working with lignocellulose-rich substrates with low DM (approx. 30%), and only the long side of the fibre seemed to be affected after passage (Brückner et al. 2011).

Separation of sand, smaller and larger stones and metals by gravitation is not included in solid disintegration systems. Those objects will be fed into the digester building up sediment that has to be removed by emptying the digester. This can shorten the interval between opening up the digester for overhaul.

Sparks can occur when chain mill hits metals and stones that under unfortunate circumstances can lead to ignition and burning of disintegrated manure with rather high dry matter content.

11.3.8 Improved biogas production in batch tests

The common way to determine the influence by disintegration is to compare the biogas production before and after disintegration in batch tests. There is a large variation in the results (Table 11.15). The biogas production can be improved (or made worse) by:

- 0 to 68 % by disintegrating deep litter manure/cattle manure
- -10 to 69 % by disintegrating ley crop
- -7 to 30 % by disintegrating wet land grass/road grass
- -6 to 7 % by disintegrating rye crop silage

There is also a large variation in the results between tests with the same disintegration technology. One example on this are tests with a hammer mill on deep litter manure, where the manufacturer Huning reported 6% improved biogas production while Brückner et al. (2011) reported 68% more biogas. Another example are tests with a device called “Grubbens deflaker” for which DANETV (J.no. 1003) reported no improved biogas production with cattle manure, while Lindmark et al. (2012) reported 69% more biogas with ley crop. It is obviously difficult to know how reliably to believe in the yield improvement potential of disintegration.

11.3.9 Economical reflection

In general, studies and reviews of technologies for disintegration of lignocelluloses-rich biogas substrate describing economy for the technology have focused on investment cost, energy requirement for disintegration and most importantly the improved specific methane production during batch digestion test. The aim of this chapter is to point out a more balanced description and to define some more parameters that can have a major influence on the economical outcome of a small-scale biogas plant using mechanical disintegration for pre-treatment of deep litter manure before co-digesting it with cattle slurry.

Improved biogas production in CSTR digestion

A typical specific volumetric production of biogas for a CSTR running in the mesophilic temperature range and digesting cattle slurry (8% DM) is 0.9-1.0 m^3/m^3 digester volume and day, when the manure generates 20 m^3 biogas/ton and when the hydraulic retention time is approx. 20 days.

As mentioned before, a digestion process can be optimised by improving the energy content of the substrate mix digested. In this case adding the energy-richer substrate deep litter manure with a simultaneous reduction of the amount of slurry facilitates an increased specific volumetric biogas production and lead to a higher income in the CHP-production. However, there are both microbiological and technical limitations to this strategy. Edström et al. (2013) have shown in a shorter test at a farm-scale plant that it is possible to digest manure mixtures with 2/3 of the total biogas production coming from deep litter manure and with a total biogas production of 32 m^3/ton (Table 11.10) This is close to the level Gregersen (1998) stated as necessary for profitable biogas production. The achieved specific volumetric production in the test at an organic load of 3.1 kgVS/m^3 day and a 33 day hydraulic retention time was 1.0 m^3/m^3 digester volume and day. The limitation to increase the organic load further was caused by frequent operational disturbance connected to the disintegration of deep litter manure at the farm plant.

One rather optimistic estimation is that is both technical and biological possible to increase the organic load significantly to 4.5 kgVS/m^3d with a manure mixture if the hydraulic retention is longer than 25 days and this will result in a volumetric biogas production of 1.5 m3/m3 digester volume (Table 11.13). The DM content of the manure mixture is calculated to 15% with a VS-content of 85% and it can produce 40 m^3 biogas/ton. This can be compared with information from the German evaluation program “Biogas Messprogram II” (2009) according to which biogas plants with one digester, using energy crop as the main substrate, had an average volumetric biogas production of 1.7 m^3 biogas/m^3 digester volume, average organic loading of 4.5 kgVS/m^3d and a retention time often longer than 40 days.

Table 11.13. Description of an assumed biogas plant with 640 m^3 digester volume co-digesting deep litter manure and slurry. Deep litter manure is the main source for the biogas production.

Slurry	15	Ton/day
Deep litter manure	8	Ton/day
Organic load	4.5	Kg VS/m^3 day
HRT (inflow)	28	Days
Digester volume (wet volume)	640	m^3
Biogas production	1.45 : 40	m^3 biogas /m^3 digester : m^3/ton feedstock
Biogas production	5300	kWh/day
Deep litter manure	65%	Contribution to total biogas production

Technical challenge

In addition to finding a robust and cost-effective mechanical disintegration for deep litter manure, another technical challenge for using deep litter manure as main substrate in a CSTR process is to keep the digester completely mixed without addition of diluting water and maintain a reasonable electrical requirement. Based on the mass losses through biogas production, the DM in the digester will be approx. 10%. This is rather high for CSTRs, but the major contributors to mixing properties within the digester are the fibre content and the fibre length.

Electricity requirement and production

The electrical requirement should be kept on a reasonable level, both for disintegration and for mixing the digester. In Table 11.14, there is a calculated example with focus on the electricity requirement versus additional electricity production by a CHP-unit by improved biogas production from the described hypothetic biogas plant described in Table 11.13.

Table 11.14. Calculation of electricity requirement for running the biogas plant described in Table 11.13.

Electricity requirement in…		
Traditional slurry digestion	4	kWh electricity/kWh biogas
Disintegration of deep litter	0.035	kWh electricity/kg DM (Table 6 & 7)
Feeding the disintegration	0.040	kWh electricity/kg DM (Table 6 & 7)
Traditional slurry digestion	212	kWh/day
Disintegration of deep litter, including feeding	168	kWh/day
Disintegration and digestion	380 : 7.2	kWh/day : kWh electricity /kWh biogas
Energy balance as electricity		
CHP electrical efficiency	35%	of energy in biogas
Electricity production	1855	kWh/day
Total electricity requirement for running biogas plant incl. disintegration of deep litter manure	20%	of produced electricity by CHP
Improved biogas production from deep litter manure to cover electrical requirement for disintegration incl. feeding	14%	higher methane production

In the example, the specific methane production from the solid manure has to improve by 14% to cover the electrical requirement for disintegration including feeding. This is not including any increased electricity for mixing the digester and other tanks. Based on Tables 11.15 and 11.16, it is quite uncertain whether the disintegration of solid manure will improve specific methane production to the degree required. Hence, a considerable amount of improved electrical production connected to improved biogas production will be used running the disintegration unit. Taking this in consideration, the capital and maintenance cost for running the disintegration step has to be financed by increased income from heat from the CHP unit, reduced cost for handling of solid manure and improved value of the nutrient, originating from the solid manure.

Nevertheless, disintegration of deep litter manure facilitates improvement in the specific volumetric biogas production for a biogas plant co-digesting slurry with deep litter manure, compared with digesting only slurry. This alternative way of optimising slurry digestion is poorly investigated, but it seems that an improved specific volumetric biogas production up to 50%, if the hydraulic retention time is close to 30 days, is quite possible. This optimisation space is approx. 3 times higher than the minimum improved biogas production (14%) needed to produce the electrical requirement for the disintegration. Using this optimisation space, there will be a significant surplus of produced electricity that evidently can also contribute to financing the capital and maintenance costs for running the disintegration.

A major obstacle with co-digesting deep litter manure with slurry is that the DM content and amount of fibre in the digester will increase, making it more difficult to keep it complete stirred. Disintegration decreases this challenge by chopping the fibres into smaller size, but the viscosity is still increased. The mixers will consume more electricity due to increased need of mixing. There is also a limit as to how much the DM content in the digester can be increased and it depends on plant-specific choices of mixing technology. E.g. propeller-type mixers can only mix up to a degree of DM. Gas mixing, i.e. vacuuming the biogas produced and releasing it from the bottom of the digester to bubble through the digester content would not face such challenge nor significantly increase the electricity demand of the biogas plant.

Table 11.15. Review, disintegration, required electrical demand and improved biogas production in batch tests. Used abbreviations: H M= Hammer Mill; CM = Chain Mill; K M = Knife mill (meat mincer); E = Extruder; Def = deflaker (rotor disc), Dis = dispenser (rotor disc); S = Solid disintegration technology; L = Liquid disintegration technology.

Mill		Substrate		Disintegration	Disintegration and feeding	Improved	Specific methane production after disintegration	Batch	Reference
			DM %	Req. Elec. kWh/kg DM	Req. Elec. kWh/kg DM	biogas %	l/kg VS	Digest. Days	
H M	S	Deep litter, sow	33%	0.018	n. a.	6%	472$^{x)}$	39	Huning 2013
H M	S	Deep litter, cattle	33%	n. a.	n. a.	68%	325$^{x)}$	28	Brückner et al. 2011
H M	S	Ley crop silage	44%	0.014	n. a.	30%	593$^{x)}$	39	Huning 2013
H M	S	Ley crop silage	26%	0.023	n. a.	19%	551$^{x)}$	39	Huning 2013
C M	S	Ley crop silage	n. a.	n. a.	n. a.	-10%	705$^{x)}$	25	Brückner et al. 2011
C M	S	Rye crop silage	n. a.	n. a.	n. a.	-6%	600$^{x)}$	25	Brückner et al. 2011
C M	S	Horse manure	Approx. 30%	0.033	n. a.	14%	205	35	Oechsner et al. 2012
E	S	Deep litter	25-45%	0.024	0.049	30%	280	20-30 d	Lyngsø et al. 2012
E	S	Deep litter	28-40%	n. a.	n. a.	37%	220	28	Hjort et al. 2011
E	S	Deep litter	28-40%	n. a.	n. a.	28%	260	90	Hjort et al. 2011
E	S	Wet land grass	70-85%	0.114	0.160	30%	290	20-30 d	Lyngsø et al. 2012
E	S	Road gras	17%	0.087	n. a.	-7%	268	33	Bolduan et al. 2011
E	S	Rye crop silage	36%	0.035	n. a.	7%	305	42	Menardo et al. 2013
K M	S	Ley crop silage	37%	0.065	n. a.	0%	380	70	Nordberg et al. 1997
K M	S	Ley crop silage	37%	0.030	n. a.	0%	380	70	Nordberg et al. 1997
Dis	L	Ley crop silage	35%	0.173	n. a.	56%	255	36	Lindmark et al. 2012
Def	L	Ley crop silage	35%	0.023	n. a.	69%	235	36	Lindmark et al. 2012
Def	L	Cattle manure	15%	0.0002	n.a.	0%	210	30	DANETV, J.no. 1003

x) Litre biogas/kg VS. No information on the methane content in biogas.

Table 11.16. Review, disintegration, required electrical demand and improved biogas production in CSTR tests. Used abbreviations in the table: M = Macerator; TSG = Twin Shaft Grinder.

		Substrate	DM %	Disintegration Req. Elec. kWh/kg DM	Disintegration and feeding Req. Elec. kWh/kg DM	Improved biogas %	Spec. methane production after disintegration l/kg VS	Digester vol. m^3	HRT days	Organic load kg VS/m^3 d	Digest. temp. °C	Reference
M	L	Slurry	5%	0.002 – 0.026	n.a.	(-5) - (+25)	230-380	> 1000	n.a.	n.a.	n.a.	Hartmann et al. 2000
M	L	Ley crop silage	25%	0.016	0.036	n.a.	330	500	n.a.	n.a.	37	Edström et al. 2005
M	L	Horse manure & ley crop silage	30% & 25%	0.032	0.063	n.a.	n.a.	500	47	2.6	37	Edström et al. 2005
TSG	L	Deep litter	28%	0.022 – 0.048	0.11 – 0.16	n.a.	190	260	33	3.1	38	Edström et al. 2013
C M	S	Horse manure, Nawaro and slurry	n.a.	0.033	0.021	40	250	923	76	2.5	n.a.	Jungbluth et al. 2013
K M	S	Ley crop silage	37%	0.030-0.065	0.080-0.11	n.a.	280-290	23	40	4.5-5.0	37	Nordberg et al. 1997

11.4 Post-digestion

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Most of the biogas plants digesting manure are of the CSTR-type. Substrates are fed into the digester daily and totally mixed into the digester content. Digestate is also withdrawn daily, resulting in some inevitable short-circuiting of substrates. The true hydraulic retention time of the substrate is never quite as long as the calculated (digester liquid volume divided by daily feed volume). Some of the fresh substrate will be withdrawn nearly directly from the digester.

When the digester content is totally mixed, all the digestate withdrawn is biologically active and will continue to be so also in the next vessel following the digester. When combined with the fact that some of the fresh substrate short-circuits the digester, significant biogas production will occur from the digestate. If the plant is operated with a too short retention time, even more biogas will be formed in the vessel receiving the digestate due to higher amount of undegraded organic matter in the digestate.

There is ample evidence of the post-biogas production from digestates and their emission/energy potential (e.g. Kaparaju & Rintala 2003, Weiland 2003, Hansen et al. 2006, Gioelli et al. 2011, Menargo et al. 2011). In case this digestate is stored in open storages without gas collection and utilisation, it will result in high methane emissions which undermine the positive effects of manure-based biogas totally. Simultaneously a significant source of energy and revenues for the plant are lost. The post-biogas has been reported to amount to approximately 15-20% of all biogas produced in biogas plants (Weiland 2003, Luostarinen et al. 2013).

Post-digestion does not necessarily mean a second digester in series with the main one. It can be a simpler solution, e.g. a storage tank with gas-tight cover, minimal mixing to ensure gas release and contact between the organic matter and microbes, no temperature control, but merely good insulation to maintain the temperature as high as possible after the digester. The post-digestion tank can be the only storage tank on farm-scale biogas plants, in which case its retention time is maximal. It can also be part of the storage volume with a shorter retention time.

It is highly advisable to have a gas-tight post-digestion tank at all biogas plants. Additionally the retention time of the main digester has to be sufficiently long for the substrates used. The post-biogas needs to be collected and utilised in energy production, together with the digester biogas, so as not to jeopardise the environmental performance of the biogas plant. Simultaneously also ammonia emissions are prevented in this step. Still, the final storage of the digestate should also ideally be covered and the temperature of the digestate lowered immediately after the post-digestion to minimise microbial activity and thus emissions during storage.

11.5 Co-substrates for slurry

Sari Luostarinen

Co-substrates are added into slurry-based biogas plants in order to increase the energy yield of the biogas plants. This, in turn, improves their economy by higher income and, depending on the co-substrate, also by gate fees. Basically any organic wastes and by-products could be digested with slurry. However, there are limitations due to technology, co-substrate quality and legislation.

A biogas plant is designed for a certain type and amount of feed / feed mixture. This sets the limits to what the technology can handle and not any changes in substrates are possible. When looking for co-substrates for slurry-based biogas production, the technology of the biogas plant must, therefore, be thoroughly considered: how much and what kind of co-substrates can the existing technology (feeding solution, mixing, withdrawal, retention time) handle. From the nutrient point-of-view it is also important for farm-scale operators to consider how much additional nutrients are added into the substrate mixture. The farms need to have sufficient field area for application. They also need sufficient storage capacity which might be increased due to co-substrates.

The environmental issues related to different co-substrates have been studied vastly in work package 5 of the Baltic Manure project (Hamelin et al. 2014, Pehme 2013, Baky 2013) and elsewhere (e.g. Hamelin 2013). The baseline for LCA results is that manure-based co-substrates are the most sustainable options for slurry digestion. The use of solid manure and separated solid fraction from slurry is thus highly recommendable. Also, many wastes and by-products offer excellent co-substrates options from the perspective of the environment.

Plant biomass is the most controversial issue environmentally. While biomasses without any food or feed use are environmentally sustainable co-substrates, energy crops are not. Especially annual energy crops, such as maize, cannot be recommended from the environmental point-of-view. The main reason for this is that the field area taken by energy crops has to be replaced in some other place not to induce decrease in food and/or feed production. The resulting land use changes deteriorate the environmental benefits of using energy crops as co-substrates.

From biogas technology and economy point-of-view, the use of some energy crops as co-substrate to slurry may, however, be feasible. Their use increases the plant economy via increased energy production and many biomasses are easily degraded and suitable for the existing technologies. Especially if the energy production is subsidised, the increased energy may be a significant boost to the biogas plant economy.

Still, due to the environmental concerns, the co-substrate use of especially annual energy crops should be minimised. This should also be taken into account in the subsidy systems so that they do not support biogas production with any substrates. Manure should be given priority, along with other wastes and by-products without uses as food or feed.

12 Baltic Manure recommendations for manure-based biogas in the BSR

Sari Luostarinen & Knud Tybirk

Animal production inevitably results in manure production. Manure is usually utilised as an organic fertiliser with the focus on its nutrients. However, manure also contains organic matter and thus energy. When combining the targets of using both manure nutrients and energy, more environmental and economic benefits and also more solutions for different manure management cases can be obtained than when focusing only on the nutrients.

The energy content of manure is relatively modest due to the metabolism of the animal making use of the easily degradable organic matter in the feed. Still, the amounts of manure produced are significant and make the energy content of manure appealing for energy production. Agricultural production is energy-intensive both at the farms and in the production of mineral fertilisers. The opportunity to replace at least part of this energy consumed with renewable energy and with recycled nutrients from manure creates a win-win situation for agriculture and the environment.

There are different technologies existing and under development for harnessing manure energy potential. The targets behind the processes may differ as others link energy production to nutrient recycling and emission mitigation more strongly and others focus more on the energy and reducing manure volume. Still, all processes inevitably require consideration of energy, nutrients and emissions in the entire manure management chain also before and after the energy step.

Based on the work done in Baltic Manure, the following recommendations can be made for manure energy use.

12.1 Thermal treatment of manure requires development

Combustion and thermal gasification of manure is focused on energy production from solid manure and separated dry fraction of slurry and/or other manure-based solid processing products. The residues (ash) of these technologies contain phosphorus and trace elements which can be recycled into plant production. The plant-uptake of phosphorus is, however, lower after thermal treatment. Also the liquid fraction remaining from slurry separation can be utilised in fertilisation, thus increasing nutrient recycling. Both technologies reduce the amount of manure to be transported and applied on fields significantly. In some cases the latter alone might make manure combustion or thermal gasification appealing (e.g. large horse stables in residential areas).

However, manure combustion is a controversial issue in the BSR. While Sweden practises it in few combustion plants with reduced requirements for treatment of flue gases, most other BSR countries require the flue gases to be treated according to Waste Incineration Directive (2000/76/EC), making manure combustion economically unattractive. Moreover, thermal gasification of manure is still under development due to the relatively low energy content and high water content of manure and no installations using manure exist at the time of writing (December

2013). Another drawback is that both combustion and thermal gasification lose the valuable nitrogen in manure (except for the nitrogen directed to the liquid fraction of separated slurry).

Combustion or thermal gasification of manure is currently not recommended for manure energy use in the BSR due to not being manure technology.

With technological development and proper solutions for managing the flue gases, both technologies may in the future become more widely accepted and recommendable especially in manure surplus situations and with manures which would otherwise be costly and difficult to use.

12.2 Biogas production from manure should be promoted

Another way of harnessing the energy content of manure is biogas production. During anaerobic digestion, part of the organic matter in manure is microbiologically degraded into methane-rich biogas, while the residual mass, digestate, contains all the manure nutrients and a higher share of directly plant-available ammonium nitrogen than in raw manure. In addition, the slowly degradable carbon can be returned to the C-pool of soils. Biogas can be utilised in energy production in boilers (heat) and/or in combined heat and power production. It is also possible to upgrade biogas to a high methane content (>90%) and utilise it as a transportation fuel or in replacement of natural gas.

In the BSR, there is approximately 187 million tons of cattle, pig and poultry manure produced each year. Most of it can be found in Poland, Denmark and the northern German states with coastline to the Baltic Sea. The Russian manure production is not taken into account, but is acknowledged as significant.

According to estimations made in the project, the theoretical energy potential of this manure is 38-74 TWh (137-266 PJ) as biogas. It is, however, obvious that not all manure can be directed into biogas plants e.g. due to logistics. Thus, a techno-economical energy potential was estimated for manure produced on cattle, pig and poultry farms with more than 100 animals. The potential is then approximately half of the total, 17-35 TWh (61-126 PJ).

At the time of writing, only a small portion, approximately 4% of all cattle, pig and poultry manure is being digested in biogas plants. Thus, the potential is still largely unharnessed.

Less than 5% of the manure in the BSR is currently directed to biogas production. The unused potential is significant.

12.2.1 Solutions for solid manure required

An important thing to consider for harnessing this energy potential as biogas production is the share of slurry and solid manure types which differs from country to country. The highest share of slurry, 80%, is in Denmark, while in Poland 90-95% of all manure is solid. More generally, nearly 50% of the manure in the BSR is solid.

The importance of manure types is related to available technologies for manure digestion. While CSTR technology for slurry digestion is mature and widely used, the digestion of different solid manures requires development. Dry fermentation processes do exist, but their efficiency in relation to biogas yield and the degree of degradation is not particularly good. In order to make more effective use of solid manures, some of it can be directed into co-digestion with slurries without any pre-treatment. However, if the share of solid manure in a biogas plant with a CSTR becomes high, the resulting high dry matter content (approximately >12%) impairs the technological and subsequently also the microbiological functioning of the plant. Different mechanical pre-treatments, such as extrusion and milling, may ease this problem by disintegrating the solid manure, reducing its particle size and thus increasing its degradability in the CSTR. Still, the share of solid manure in a CSTR is limited.

Technology development for biogas production from solid manures is essential in order to harness the manure energy potential in the BSR, incl.

- **Co-digestion technologies with slurry**
- **Pre-treatment to increase degradability**
- **Dry fermentation / novel reactor designs**

12.2.2 Profitability via co-substrates for manure-based biogas

Slurry needs energy-rich co-substrates to increase energy yield and to subsequently enable profitable biogas production. Solid manure and mechanically separated solid fraction of slurry form good co-substrates for slurry, but also other societal residues are sound sources of sustainable carbon addition. For instance, pelletised straw and grass biomasses from nature conservation seem potential alternatives.

Life cycle analysis shows clearly, that maize and other annual energy crops are not environmentally sustainable co-substrates giving rise to net greenhouse gas emission (see: Baltic Manure reports on LCA). Energy crops can still be cultivated and used for biogas production though they are expensive substrates and income from the energy produced must be high to make this possible. The environmental effects using energy crop for biogas production is highly dependent on the chosen crop, but also on whether the energy crop will compete with animal feed or food production.

It is recommended to use co-substrates with slurry digestion to increase energy yield and thus profitability.

- **Manure-based co-substrates are the most recommended.**
- **Suitable societal and agricultural organic wastes and by-products are also recommendable.**
- **The use of annual energy crops should be carefully considered and minimised.**

12.2.3 *Proper management of the digestate is vital for environmental benefits*

Conventionally used technology in biogas plants leaves significant amounts of biodegradable organic material within the digested manure. By investing in a post-digestion tank at the biogas plant and collecting the biogas still emitted from the digester residue, the biogas production of the plant can be improved with at least 15-20%. Simultaneously methane emissions are minimised.

During digestion, part of the organically bound nitrogen mineralise into ammonium and thereby become more readily available for the growing plants when applied to the field. However, this increased ammonium content of the digestate demands that the manure storage and field application follow strict demands on closed storages and soil injection and/or acidification during field application. Otherwise there is a risk of jeopardising the benefits of biogas by additional ammonia emissions. In addition, the timing and dosage of digestate should fit to the crops need to avoid leaching of N and P.

Post-digestion is vital for the environmental performance of manure-based biogas production. Post-biogas must be collected and utilised in energy production.

It is recommended to cover digestate storages and to apply it on fields during growth season and using soil injection and/or acidification in order to minimise emissions.

12.2.4 *Biogas energy use according to regional needs*

Biogas production from manure can be done in farm-scale plants or in larger plants digesting manure from numerous farms. Usually, biogas is utilised in farm-scale plants for CHP production. While the use and/or selling of electricity is rarely a problem, the usage of heat from the CHP may be a bottleneck. Uses for the heat must be found in order to ensure the environmental benefits. In large-scale plants, biogas energy can often be used more efficiently. CHP production leads to a higher ratio of electricity, but also potential users for the heat (e.g. district heating) can be found due to the increased amount produced. Biogas can also be upgraded and be a substitute to fossil fuels in vehicles or be injected into natural gas grid. Development of less expensive upgrading is needed especially for smaller scale.

Moreover, biogas usage should be fit into the national energy strategy. This depends on the existence of natural gas grid, gas-driven vehicles, and well-developed CHP and district heating systems. This is quite different in the BSR countries.

Biogas energy use must be carefully planned and fit into the national / regional energy strategy. In CHP production, the use of heat must be maximised.

12.2.5 Stable and clear incentives needed to boost manure energy use

In order to promote manure-based biogas production, incentives from policy making are needed. The incentives should be made in line with the rest of the manure management chain, meaning that they should simultaneously promote and/or put prerequisites to manure handling during the digestion as well as before and after the biogas plant.

The incentives can be financial to improve profitability of biogas plants. The type of financial support should be chosen according to the country- and region-specific conditions and it can be anything from guaranteed prices for the biogas energy (e.g. feed-in tariff) and tax exemptions to investment support and specific support schemes in the agroenvironmental programme.

Most importantly, any financial support must be sufficiently high to increase manure-based iogas production. Also, manure should be given priority in the support systems to direct more manure as opposed to e.g. energy crops into biogas plants.

Incentives may also be regulatory. An example of this is the Danish requirement for municipalities to plan locations for biogas plants in order to ease the implementation of biogas production in the municipal planning system.

Overall, the incentives for manure-based biogas should be stable and guaranteed for a certain, sufficiently long period. Also, the system should be clear and flexible for different scales of biogas production. This is of vital importance to lower the risk of the investment.

Stable, guaranteed and clear incentives should be adopted to promote manure-based biogas production. The support system must be flexible for different scales and give priority to manure digestion.

12.3 Overall conclusion

In light of the work done in the workpackage on Manure Energy Potential of Baltic Manure project, the following can be concluded:

Manure-based biogas production is in many ways a beneficial part of the manure management chain. It produces renewable energy, enables recycling of manure nutrients and organic matter along with those from potential co-substrates, improves the utilisation of manure nitrogen and helps to mitigate emissions.

The most important matter to remember is that manure-based biogas production is only one step in the manure management chain. In case the measures before and after the biogas plant are neglected, potentially all the environmental benefits of the actual biogas step can be jeopardised. Thus, the importance of holistic thinking, taking into account all the steps of the manure management chain, is the only way to make all the benefits of manure-based biogas production come true.

Manure-based biogas production must be seen as one significant step in the entire manure management chain.
When promoting, planning or producing manure-based biogas, it is vital to optimise also the steps before and after the biogas plant.

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This report in brief

In this report, national scenarios for harnessing the manure energy potential as biogas have been created for all BSR. The methodologies for this task differ from country to country, as do the conditions, but all scenarios aim at replying in the following issues: locations of manure and thus its energy content in each BSR country, possible locations for manure-based biogas plants, possible amount of manure-based biogas plants in different scales, estimated investment costs and potential for job opportunities.

Finally, some important best practices and recommendations for manure-based biogas are raised. In all BSR countries, solid manures hold a significant portion of the techno-economical energy potential of manure and solutions for digestion of solid manure are needed. Moreover, all biogas plants should be equipped with a post-digestion tank to collect the residual biogas still emitted after the main digester. And the choice of co-substrates to boost slurry-based biogas production should be made wisely with preference for solid manure and other materials without food or feed use.

This report was prepared as part of work package 6 on Manure Energy Potentials in the project Baltic Manure.

About the project

The Baltic Sea Region is an area of intensive agricultural production. Animal manure is often considered to be a waste product and an environmental problem.

The long-term strategic objective of the project Baltic Manure is to change the general perception of manure from a waste product to a resource. This is done through research and by identifying inherent business opportunities with the proper manure handling technologies and policy framework.

To achieve this objective, three interconnected manure forums has been established with the focus areas of Knowledge, Policy and Business.

Read more at www.balticmanure.eu.

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Baltic Sea Region
Programme 2007–2013
Part-financed by the European Union
(European Regional Development Fund)